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DEFINITION OF EXPERIMENTS AND INSTRUMENTS FOR A COMMUNICATION/NAVIGATION RESEARCH LABORATORY

VOLUME I

EXECUTIVE SUMMARY

STUDY REPORT

DR MA - 04

DECEMBER 1972

PREPARED FOR MARSHALL SPACE FLIGHT CENTER
UNDER CONTRACT NO. NAS 8 - 27540

TRW

SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH CALIFORNIA 90278

INSTITUTE FOR TELECOMMUNICATION SCIENCES

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY

COMMUNICATIONS SATELLITE CORPORATION

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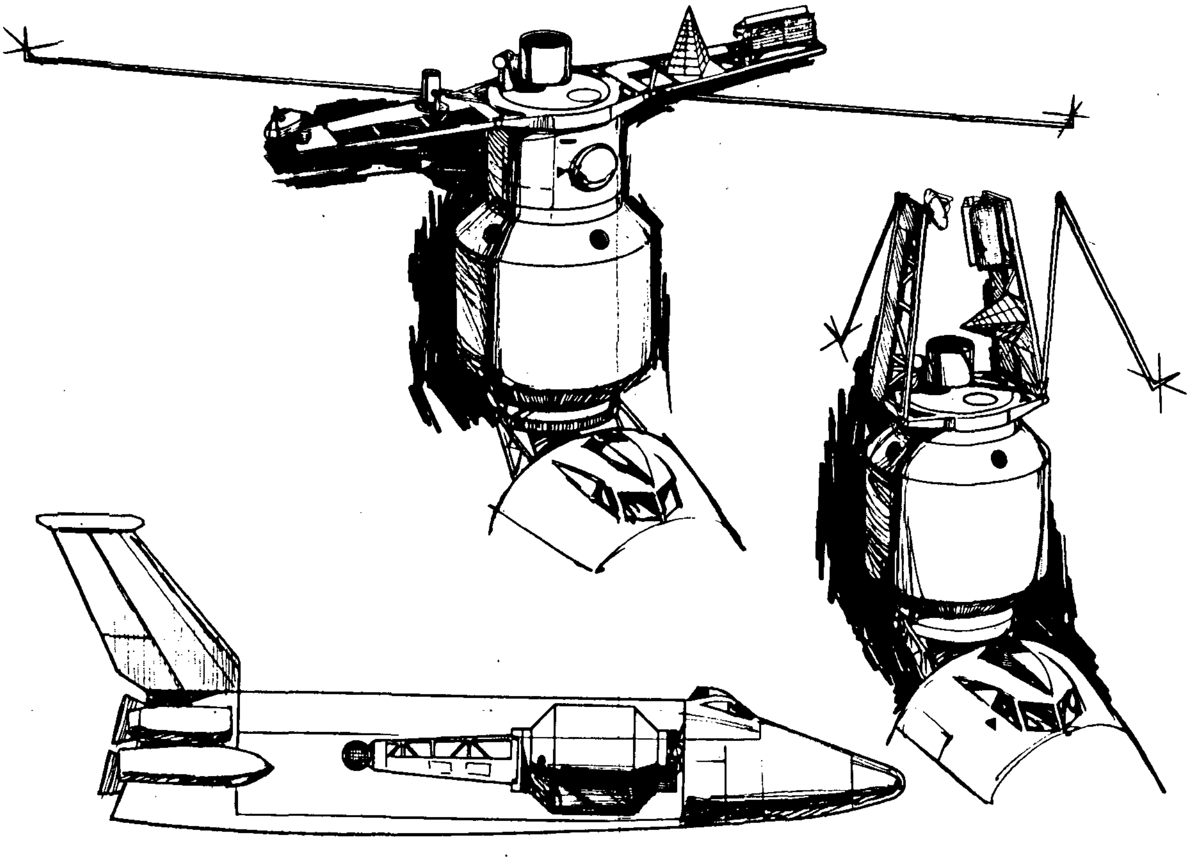

FOREWORD

The Definition of Experiments and Instruments for a Communications/ Navigation Research Laboratory study was conducted by TRW Systems Group for the NASA Marshall Space Flight Center, Huntsville, Alabama from June 1971 through October 1972 under Contract NAS8-27540; funded at $288, 000. The effort was contractually supported by the McDonnell Douglas Astronautics Company, the Institute for Telecommunication Sciences, and the Communications Satellite Corporation.

This document presents an executive summary of study work and has been prepared in accordance with NASA Data Requirement MA-04. The Study Report consists of the following:

Volume I	Executive Summary
Volume II	Experiment Selection with Appendix on Experiment Descriptions. Study Task 1
Volume III	Laboratory Descriptions. Study Tasks 2, 3, 4 and 5
Volume IV	Programmatics - Development Schedules, Costs, and Supporting Research and Technology. Study Task 6

The contractor study team operated under the technical direction of Mr. Charles Quantock, COR/Study Manager, Mission and Payload Planning Office, Program Development, at NASA Marshall Space Flight Center and Mr. Eugene Ehrlich, Office of Applications, NASA Headquarters, Washington, D. C. Other NASA centers and offices provided significant advice, consultation, and documentation in support of study task activity.

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GLOSSARY

AAFE	Advanced Applications Flight Experiments
ASTP	Apollo Soyuz Test Project
ATR	Air Transport Rack
ATS	Applications Technology Satellite
CAS/C	Cooperative Application Satellite/Canadian
CCIR	International Radio Consultative Committee (Comité Consultatif International Radio)
CNRL	Communications/Navigation Research Laboratory
COMSAT	Communication Satellite Corporation
CONUS	Continental United States
COR	Contracting Officer's Representative
CVT	Concept Verification Test
dB	decibel
DOD	Department of Defense
DPD	Data Procurement Document
DSCS	Defense Satellite Communications System
DWS	Disaster Warning Satellite
EHF	Extremely High Frequency
ELF	Extremely Low Frequency
EME	Electromagnetic Environment
EMI	Electromagnetic Interference
ERP	Effective Radiated Power
ERTS	Earth Resources Technology Satellite
ETV	Educational Television
EVA	Extra Vehicular Activity
FAA	Federal Aviation Agency
FCC	Federal Communication Commission
FY	Fiscal Year
GSFC	Goddard Space Flight Center
HEW	Department of Health Education and Welfare
Hdqrts	Headquarters
IOC	Initial Operating Capability
IR	Infrared
IRS	Internal Revenue Service
ITOS	Improved Tiros Operational Satellite

ITS	Institute for Telecommunication Sciences
ITV	Instructional Television
IRAC	International Radio Advisory Committee
KSC	Kennedy Space Center
LES	Lincoln Experimental Satellite
LRC	Langley Research Center
MDAC	McDonnell Douglas Astronautics Company
MDAC-E	McDonnell Douglas Astronautics Company-East
MDAC-W	McDonnell Douglas Astronautics Company-West
MSC	Manned Spacecraft Center
MSFC	Marshall Space Flight Center
MSFN	Manned Space Flight Network
MSM	Manned Support Module
NASA	National Aeronautics and Space Administration
NOAA	National Oceanographic Atmospheric Agency
OTP	Office of Telecommunication Policy
PI	Principal Investigator
PLACE	Position Location and Aircraft Communication Experiment
PO	Purchase Order
psi	pounds per square inch
R&D	Research and Development
RAM	Research and Application Module
RF	Radio Frequency
RFI	Radio Frequency Interference
RTOP	Research and Technology Operating Plan
SATS	Small Applications Technology Satellite
SHF	Super-High Frequency
SOAR	Shuttle Orbital Applications Requirements
SRT	Support Research and Technology
STARS	Stellar Tracking Attitude Reference System
SVD	Space Vehicles Division
TDRE	Tracking and Data Relay Experiment
TDRS	Tracking and Data Relay Satellite
TDRSS	Tracking and Data Relay Satellite System

UHF	Ultra-High Frequency
USGS	United States Geologic Survey
VHF	Very-High Frequency
VLF	Very-Low Frequency
VSWR	Voltage Standing Wave Ratio
WARC	World Advisory Radio Committee
WBS	Work Breakdown Structure
WTR	Western Test Range

TABLE OF CONTENTS

INTRODUCTION

One feature of the future NASA Earth orbital flight program may be a series of manned missions with Space Shuttle supported laboratories to perform communications/navigation research. This Definition of Experiments and Instruments for a Communication/Navigation Research Laboratory (CNRL) study is one of several Space Shuttle sortie mission definition studies currently sponsored by NASA to obtain planning information relative to forthcoming Shuttle/payload operations in Earth orbit.

This volume summarizes the CNRL study. It includes NASA objectives, relationship of the CNRL concept to other NASA efforts, the study approach and assumptions, a survey of task results, and recommendations for additional effort.

Scope

This Phase A study was performed over a 15-month time period, was composed of six major task areas of work, and resulted in contract deliverables of a four-volume Study Report and fabrication of a 1/20 scale model of a Space Shuttle supported Early Communications/Navigation Research Laboratory.

Background

Rapidly emerging as prime candidates for NASA Space Shuttle missions of the 1980-1990 time period are flights to perform research in various disciplines of science and applications. One area that could enhance the economic and technological benefits to mankind, through application of space technology, is experimentation for future communication/navigation systems. There are potential advantages in Earth orbital flights of Space Shuttle supported manned laboratories. This concept — of a Comm/Nav Research Lab operating in Earth orbit on Shuttle missions — embodies new principals that capitalize on the capabilities of man-tended facilities in space and on the commitment to simplification of space hardware. The concept focuses on development of systems for space operations that emphasizes the critical factors of commonality, reusability and economy.

The criteria of commonality, economy, and reusability are best put forth in the concept of the general purpose laboratory for a given experimental discipline area. The existing Skylab program, although multi-disciplined, is the first step toward the concept of a laboratory in space. The CNRL as conceived, is such a general-purpose laboratory that could accommodate a wide variety of Comm/Nav experiments.

Present testing and experiment programs in this discipline rely heavily on using unmanned technology satellites, such as the Applications Technology Satellite (ATS) and the proposed Small Applications Technology Satellite (SATS).

The CNRL would be a space laboratory in which man may effectively increase experiment efficiency by certain observations, modifications, setup, calibration and limited maintenance steps. In addition, man may monitor experiment progress and perform preliminary data evaluation to verify proper equipment functioning and may terminate or redirect experiments to obtain the most desirable end results. The flexibility and unique capabilities of man as an experimenter in such a laboratory will add greatly to the simplification of space experiments and this provides the basis for commonality in many of the supportive

subsystems, thus reaping the benefits of reusability and reduced experiment costs.

It is anticipated that such a laboratory can complement the various unmanned programs in this discipline by providing a facility for testing and evaluating future experiments and systems, thereby, paving the way for operational systems of the future.

During the study, a suggested Comm/Nav program of experiments was developed and time-phased between Early, Growth, and Total Comm/Nav Research Laboratory concepts. Heavy emphasis was given to the Early Laboratory — its experiments and configuration. The approach was to develop a versatile, low-cost facility that would accommodate a variety of Comm/Nav experiments on Shuttle sortie (seven-day) missions.

Study Team

This study was performed for the Marshall Space Flight Center by a contractor team led by the TRW Systems Group and supported by:

- McDonnell Douglas Astronautics Company, Huntington Beach, Calif. Subcontractor for: experiment definition/description, conceptual design of major laboratory equipment and experiment instrumentation systems and operations analysis, laboratory conceptual design, and definition of cost, schedule, and SRT requirements.
- Communications Satellite Corporation, Washington, D. C. Technical consultant for survey of international scientific and technical community for candidate experiments, especially in the areas of advanced communication techniques and development of criteria for experiment selection and time-phasing and experiment definition.
- Institute for Telecommunication Science, Boulder, Colorado. Technical consultant for development of candidate experiments in the field of electromagnetic propagation and interference and development of criteria for experiment selection and time-phasing and experiment definition.

Study Conclusions

The goal of Communications and Navigation research is to facilitate continued and expanded application of space technology to better serve the national and international needs. For communications this applies to earthbound, airborne, and spaceborne terminals; and for navigation the goal is associated with vehicle positioning and traffic control.

A manned laboratory in Earth orbit to conduct Comm/Nav research could further this goal. A well defined and properly time-phased set of experiments performed in Comm/Nav laboratories, could contribute significantly to providing answers to the problems of future operational systems.

It is concluded that manned Comm/Nav Research Laboratories, Shuttle Orbiter supported, in Earth Orbit would be practical and effective, and could accommodate a large group of useful experiments. Specifically:

a) The experiment program for CNRL should be periodically reviewed to insure that it complements unmanned spaceflight experiments, is cost effective for implementation, and is tuned- and time-phased to operational problems.

b) All segments of the Shuttle Orbiter laboratory configuration and subsystems are considered technically feasible.

c) The experimental data derived from CNRL flights could have immediate application in solving urgent problems (frequency conservation, air traffic control, reentry blackout, system/component development).

d) Results could be useful to other disciplines (Radio Astronomy, Earth

Resources, Meteorology, and Plasma Physics).

e) Experiment data will be of value to many government, industry, university users.

f) The experiment common core equipment can be adapted to several types of laboratory configurations, and can expand in use as the laboratory concept evolves from Early Laboratory configurations to future options.

g) Many experiments are ideally suited to conduct on comm/nav Sortie quick reaction, multi-discipline or dedicated to (Comm/Nav only) Sortie Lab missions.

h) Several potential cost savings areas are identified:

- Development of a Standard Commercial Equipment Specification that would enable commercial items to be modified and used on manned space missions.
- Commonality as applied to experiment equipment and instrument assignment and operations.
- Employment of modularity schemes in approach to performing operational functions and equipment/instrument arrangements.
- Proper use of the experimenter crew for reconfiguring experiments so as to maximize the amount of data acquired in a given time.

STUDY OBJECTIVES

The purpose of the study was to develop conceptual designs for a manned, Space Shuttle sortie mission laboratory capable of supporting a wide variety of experiments in conjunction with communications and navigation research.

Specific study objectives:

1) Define experiments and experiment requirements.
2) Identify major laboratory and experiment equipment and instrumentation.
3) Develop conceptual designs of major laboratory and experiment equipment and instrumentation.
4) Perform systems and operations analysis in support of the CNRL design.
5) Develop conceptual designs of the CNRL.
6) Develop, cost and SRT requirements.

These six objectives were the subject of the six tasks associated with the Study Plan. The central theme of the derivation of Comm/Nav experiments is reflective of the following questions:

- What are the space experimental measurements needed to further develop Comm/Nav technology so as to optimize the use of the electromagnetic spectrum for Comm/Nav satellite systems?
- Who are the users of the experimental data and how may they be categorized?
- What services are required for, or desired by, these users?
- How may space technology provide these services?
- Can decisions be made as to the best system approach to experiment implementation? For instance, how should space experiments be performed in low-orbital manned research facilities, and how should they relate to automated, unmanned spacecraft, some of which operate at geosynchronous altitude?
- Is the required technology available to properly define experiments and their requirements?
- Is sufficient information available for engineering design of economical space laboratories to house and support the experiments?

This study was predicated on providing concepts of space research activities for future Comm/Nav studies structured well enough for NASA planning and for the derivation of laboratory requirements, but flexible enough to permit change as additional Comm/Nav needs and objectives become defined.

RELATIONSHIP TO NASA PROGRAMS

The Comm/Nav Research Lab project relates to both current study efforts and to future flight systems.

This CNRL study was structured and timed for data exchange with related NASA-sponsored studies of the Space Shuttle, Shuttle payloads, potential laboratory host vehicles, and Comm/Nav technology so that mutual benefits could be realized.

In regard to future flight systems, a major objective in selecting and phasing Comm/Nav Laboratory experiments is to ensure the collection of timely data which can be used to improve the designs of projected operational systems. Of particular value would be information, such as that obtained from propagation and radio interference measurements, which could be used to optimize the use and reuse of allocated frequency bands. The experiments should also complement those performed using concurrent unmanned spacecraft, taking full advantage of the special benefits to be derived from low-orbit tests, such as increased spatial resolution of RF sources, the possibility of receiving very low-level signals, and the changing geometry resulting from the spacecraft motion.

- SHUTTLE PHASE B
- SPACE STATION PHASE B
- RESEARCH AND APPLICATION MODULE (RAM)
- SHUTTLE ORBITAL APPLICATIONS/REQUIREMENTS (SOAR)
- ORBITAL ASTRONOMY SUPPORT FACILITY
- EARTH ORBITAL EXPERIMENT PROGRAM AND REQUIREMENTS
- COMM/NAV AAFE AND SRT DEVELOPMENTS
- OSSA COMM/NAV PROGRAM REVIEW
- DOD COMM/NAV (UNCLASSIFIED) PROGRAM REVIEW
- SHUTTLE PAYLOADS (PHYSICS, EARTH OBSERVATIONS, MATERIALS, SCIENCES, ASTRONOMY)
- SORTIE PAYLOAD CRITERIA
- LAUNCH SITE OPERATIONAL CONCEPTS
- MSFC SORTIE LAB PROJECT
- 1971 NASA BLUE BOOK, VOLUME V

The CNRL Study interacted with these related studies in the areas of systems definition and/or experiment descriptions.

PROGRAM	CALENDAR YEAR '72	'73	'74	'75	'76	'77	'78	'79	'80	'81	'82	'83	'84	'85	'86	'87	'88	'89	'90
SKYLAB		■	■																
CSM FLIGHTS		ΔΔ	Δ																
INTERNATIONAL DOCKING (ASTP)																			
POTENTIAL FLIGHTS				Δ	Δ														
PROJECTED OPERATIONAL SYSTEMS																			
INTELSATS	Δ						Δ						Δ						Δ
DOMSATS				Δ		Δ		Δ			Δ			Δ				Δ	
AEROSATS					Δ							Δ					Δ		
TDRS						Δ	Δ					Δ				Δ			
MILITARY SATS	Δ					Δ					Δ							Δ	
POTENTIAL SOURCES OF RESEARCH DATA																			
ATS		Δ		Δ	Δ			Δ			Δ	Δ		Δ		Δ			Δ
SATS								Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	Δ	
DWS								Δ	Δ										
LES	Δ			Δ	Δ				Δ					Δ					
FOREIGN PROJECTS		Δ			Δ						Δ					Δ			
COMM/NAV/RESEARCH LAB										▬	▬	Shuttle Support Flights							▬

CNRL missions should be time phased to complement R&D flights of automated spacecraft to produce useful data applicable to operational systems.

METHOD OF APPROACH AND PRINCIPAL ASSUMPTIONS

Major assumptions and guidelines that directly influenced the study approach together with the study logic are presented in this section.

Assumptions

- Initial CNRL operational capability is 1979 or 1980.
- CNRL accommodated in the Sortie Lab or RAM type host vehicle which in turn is attached to the Space Shuttle (later the Space Station). The CNRL in itself is a laboratory facility — not a spacecraft.
- CNRL launch and earth return by Space Shuttle. Nominal Shuttle Sortie mission (EARLY LAB) is seven days.
- Host vehicle to provide an O_2-N_2 cabin atmosphere of 14.7 psi.
- Standard attitude of the Shuttle attached CNRL is local vertical. Variation shall be within the constraint imposed by Shuttle attitude control expendables.
- Shuttle orbital painting is ± 0.5 degree with 0.01-degree/second maximum drift rate in each axis. If increased accuracy needed, the necessary equipment provided by experiment or by the CNRL.

Guidelines

- CNRL to progress from EARLY LAB to GROWTH LAB to TOTAL LAB. GROWTH and TOTAL LAB configurations/missions to be future options that evolve from EARLY LAB design and mission experience.
- Study scope limited to definition of experiments, laboratory equipment, and experiment instrumentation housed within the Sortie Lab or RAM and to identification of support requirements such as electrical power, thermal control, data storage, and experimenter crew time.
- CNRL to support type of experiments identified during the study.
- Operating orbit characteristics determined from experiment requirements.
- CNRL equipment/instrumentation designed for on-orbit replacement and retrofitting and for on-Earth refurbishment and update.
- Use off-the-shelf equipment when it minimizes development costs and adheres to required safety standards.
- Data Relay Satellite System (DRSS) may be available.
- All materials selected for use in pressurized areas to be non-toxic, non-inflammable, and non-explosive in accordance with safety standards.
- All four crew members (two flight plus two experimenter crewman) to be in orbiter cabin for launch and landing.
- Since Shuttle orbital altitude, inclination, and payload weight are interrelated, the CNRL operational orbit is function of host vehicle and lab equipment design. For planning — Shuttle supported CNRL altitude limits are 100 to 470 n. mi. and inclination limits are 0 to 90 degrees; however, the total mission payload weight will determine if one or both of these parameters must be constrained.

In addition to these assumptions/guidelines, other important considerations are related to the CNRL concept. These other considerations pertain to:

- Minimum early year funding.
- Candidate experiment program independent, as much as possible, from variations in year-to-year funding for Comm/Nav space research.
- Candidate experiments to provide useful data from low altitude, manned, short-duration orbital (seven-day) missions. Results, where necessary, can be extrapolated to synchronous orbit Comm/Nav systems.
- Maximum use of existing common core support and controls/display hardware for experiment conduct.
- Comm/Nav experimentation measurements applicable to other disciplines — physics and meteorology.

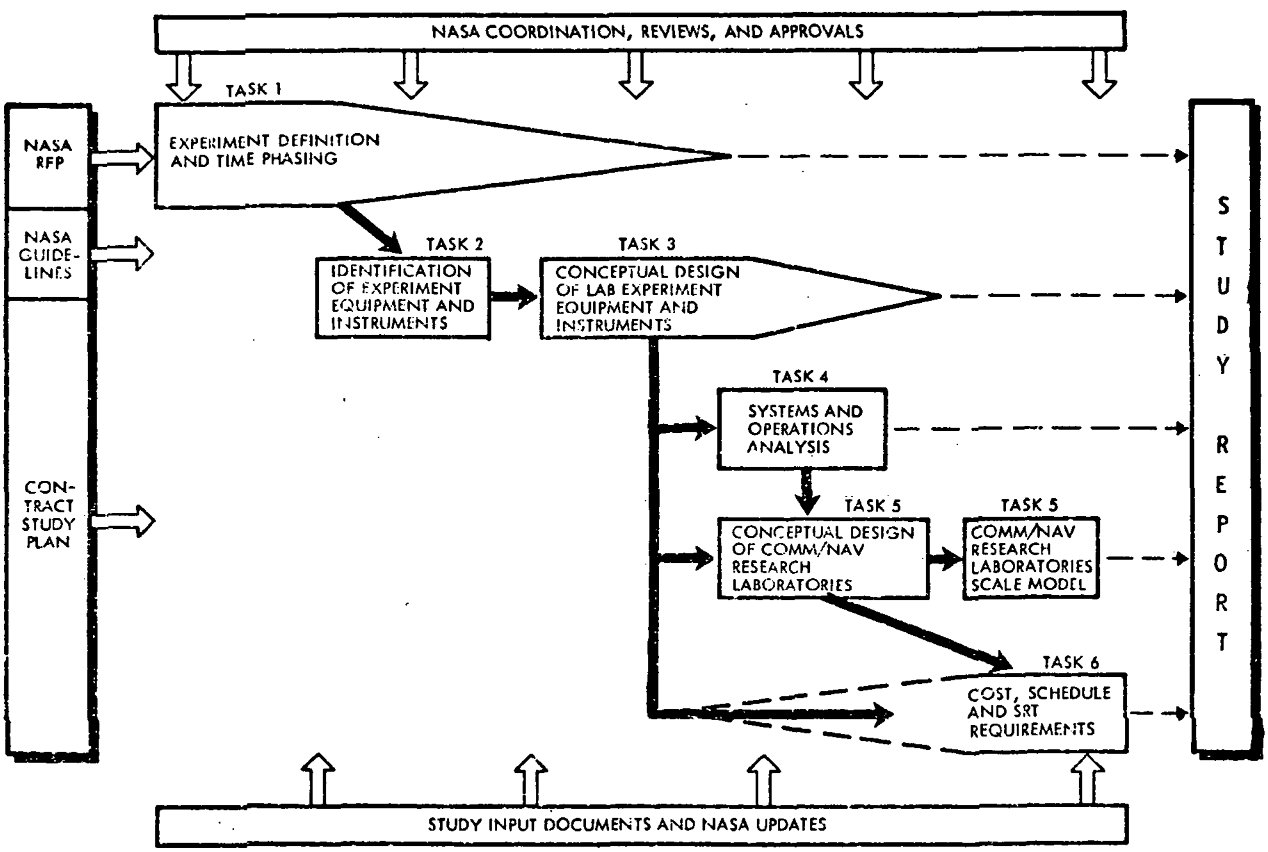
- Applied early benefits from CNRL research.
- Maximum user participation.

Study Logic

The CNRL study consisted of six major tasks whose output is a description of 18 candidate experiment classes time-phased from 1980 to 1990, equipment/instrumentation lists for these 18 experiment classes, a conceptual design of an EARLY CNRL, ideas on the makup of future configuration options beyond the EARLY Lab, mission planning data, and programmatic (cost, schedule and SRT) information on the CNRL program. A further output was a 1/20 scale model of an EARLY CNRL, showing its interfaces with the Shuttle Orbiter and how the seven experiment classes selected for conduct on the EARLY Lab are accommodated.

The key events that had major impact on study results and conclusions were:

- Extensive solicitation from sources within industry, government, university and international organizations for candidate CNRL experiments applicable to low orbit, manned, short duration missions where the measured data would be useful to the design or operation of future Comm/Nav operational systems.
- Survey of commercial hardware suppliers for product information relative to the direct use or adaptation of commercially available equipment/instrumentation to manned, earth orbital, laboratories.
- The NASA direction to carry the evolutionary concept of experiment conduct and laboratory development throughout the study but to concentrate the study effort to emphasize the experiments and configuration of the EARLY (1980-1985) CNRL.
- The NASA direction to base the EARLY CNRL configuration on utilizing the Sortie Lab and pallet as the host vehicle.



Study Logic and Task Relationships

BASIC DATA GENERATED AND SIGNIFICANT RESULTS

The six study tasks are summarized in this section. In essence, the study attacked the following questions:

1. Is it feasible to perform useful comm/nav, experiments from low orbit, during short duration Shuttle Sortie missions in a manned laboratory?

2. Is the evolutionary, growth concept of both comm/nav space research and laboratory capability practicable?

3. Can off-the-shelf hardware be used to conduct comm/nav experiments in a manned, Shuttle supported laboratory?

Study conclusions answer yes to the first two questions and a partial yes to the third. These answers are embodied in the study generated information and results.

Experiment Definition and Time Phasing (Task 1)

Communication and navigation experiments directed at acquiring research data, advancement of development concepts, and demonstration/testing of hardware components and systems could lead to improvements in:

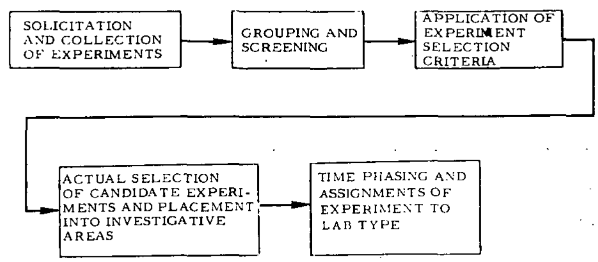
- Point-to-point information networking
- Multiple access data collection
- Navigation/traffic control
- Data relays
- Broadcast TV

which in turn, could result in benefits to many users.

In order to postulate the configuration, size, and missions operations of a Space Shuttle manned Comm/Nav Research Laboratory it was necessary to derive a candidate program of comm/nav experiments for conduct in the laboratory.

NASA COMM/NAV PROGRAM ELEMENTS	PARTIAL LISTS OF BENEFITS TO USERS
Point to Point Communications/Information Networking Broadcast TV	• Lower Telephone Rates • More Reliable, Quicker Service • More Efficient Business Transactions • Extension of Domestic Communications to Include Better Educational, Medical, Law Enforcement, Earth Resource Management, Etc., Services to Heavily Populated and Rural Areas • More Secure and Reliable Global Military Networks and International "Hot Line" Services
Multiple Access/Data Collection	• Improved Weather and Hurricane Forecasting Services and Agriculture, Mining, Water Control, Fishing and Other Earth Resource Control Operations
Data Relay	• More Efficient, Less Expensive Relay of Collected National and International Data to Centralized Data Processing Centers
Navigation/Air Traffic Control	• Safer, Quicker Air Transportation Services Through Better Air Terminal Control, Collision Avoidance and Improved Search and Rescue Operations

NASA's Future Comm/Nav Program Elements and Their Potential Benefits



Experiment Selection Methodology

Experiment Selection Criteria

Five basic elements were important in deciding what experiments to include in the makeup of a manned space comm/nav research program.

- Usefulness
- Timeliness
- Cost effectiveness
- Experiment duration and orbital considerations
- Requires involvement of man

If a manned Comm/Nav Research Laboratory, operating on a seven day Sortie mission while attached to the Space Shuttle Orbiter is to be effective, the experimental research must relate to some future problem or service.

CRITERIA	DEFINITION	COMMENTS
USEFULNESS	• JUSTIFIABLE NEED ON THE BASIS OF IDENTIFIABLE END USES IN NATIONAL INTEREST • IMPLIES EMPHASIS ON RELEVANCE RATHER THAN ON RELATED FUNDAMENTAL RESEARCH	• SUBJECTIVE MEASURE • DIFFICULT TO QUANTIFY • DOLLAR NOT ONLY BENEFIT • RELATED FUTURE SPACE PROGRAMS ARE FRAGILE • UNRELATED BENEFITS MAY BE SIGNIFICANT • FOCUSES ON UTILITY OF LOW ORBIT
TIMELINESS	• RESULTS ONLY VALUABLE IF AVAILABLE IN TIME TO BE USED FOR INTENDED APPLICATIONS • MUST ASSUME OTHER COMPETING SOURCES OF DATA – INTERNATIONAL AND NATIONAL • IMPLIES RESULTS WILL BE COMPATIBLE WITH AND COMPLEMENT THOSE OF UNMANNED SPACECRAFT	• MOST OUTPUTS WILL BE MERGED WITH THOSE FROM OTHER SOURCES • INFORMATION GAPS TEND TO CLOSE UP LIKE TRAFFIC GAPS • 10 - 15 YEAR SPAN INVOLVED MAKES UNEXPECTED SCIENTIFIC DEVELOPMENTS HIGHLY LIKELY
COST EFFECTIVENESS	• A MEASURE OF THE EXPENSE INVOLVED AND RESULTS OBTAINED (QUANTITY AND QUALITY) • USED TO COMPARE THE SUITABILITY OF PROPOSED APPROACHES	• $\frac{\text{QUANTITY X QUALITY}}{\text{COST}}$ NOT OPTIMUM? • MUST INCLUDE HAZARD TO MAN • CONSIDER SALABILITY OF PROGRAM • COST APPORTIONING IS CRITICAL
EXPERIMENT DURATION AND ORBITAL CONDITIONS	• TIME REQUIRED TO PERFORM A USEFUL EXPERIMENT UNDER CNRL CONDITIONS, 7-DAY LOW ORBIT MISSION • ASSUMES OBJECTIVE IS DEMONSTRATING FEASIBILITY, COLLECTING SAMPLE DATA AND OPTIMIZING EQUIPMENT CONFIGURATION.	• WHAT IS ENOUGH DATA? • ACCURACY VERSUS QUANTITY • COMPLEX TRADEOFF BETWEEN EXPERIMENT YIELDS VERSUS # EXPERIMENTS • VALIDITY OF 7-DAY MISSION • EXTRAPOLATE DATA TO SYN ORBIT
REQUIRES INVOLVEMENT OF MAN	• EXPERIMENT NEED FOR MANUAL ADJUSTMENT, EG –ALIGNMENT –CALIBRATION –EXPERIMENT SUBSTITUTION –LOCAL CONTROL OF EQUIPMENT –COMPONENT SUBSTITUTION –DATA INTERPRETATION	• FLEXIBILITY BY APPLICATION OF INTELLIGENCE • CONTINUOUS CONTROL MINIMIZES INTERFERENCE • REAL-TIME INTERACTIVE EXPERIMENTS

Appraisal Criteria

OPERATIONAL CLASS	SPECIFIC APPLICATIONS	CANDIDATE FREQUENCIES (GHZ)
POINT-TO-POINT (TRUNK) COMMUNICATIONS	INTELSAT V, VI, ... EUROPEAN COMSAT	3.7-4.2/5.9-6.4 10.95-11.7/14.0-14.5 17.7-21.2/27.5-31.0
	MILITARY DSCS-III, IV, ...	0.3-30KHZ 0.235-0.3286 7.25-7.75/7.90-8.40
ADVANCED DOMESTIC SATELLITES	DIRECT BROADCAST TV	0.620-0.790
	ADVANCED TV, TELEPHONE DISTRIBUTION	2.5-2.690 3.7-4.2/5.9-6.4 6.625-7.125
	INFORMATION NETWORKS ALASKAN NETWORK	11.7-12.2 + 8 BANDS>40
DATA COLLECTION	ADVANCED TIROS, ERTS, ETC.	0.136-0.141,
	SEARCH AND RESCUE	0.400 - 0.470
	POSITION LOCATION OF MOBILE TRANSMITTERS	2.1-2.3
DATA RELAY	TDRS (FOR LOS)	
	TDRS/LOS	0.126-0.150 2.025-2.300 13.40-15.35
	TDRS/GROUND	13.25-14.2/14.4-15.35
	TDRS/TDRS	54.25-58.2, 59-64, 105-130, 170-182, 185-190
	TDRS (FOR DEEP SPACE)	13.25-14.2/14.4-15.35
NAVIGATION/ATC	ADVANCED AERONAUTICAL SERVICES	1.5435-1.5585/1.645-1.660 1.5585-1.6365 (COLLISION AVOIDANCE) 43-48, 66-71, 95-101, 142-150, 190-120 250-265
	DEFENSE NAVIGATION SATELLITE SYSTEM	1.5/1.6
MANNED LOW-ORBIT SPACECRAFT	SPACE SHUTTLE SPACE STATION	0.136-0.141, 2.1-2.3
DEEP-SPACE/LUNAR COMMUNICATIONS	PIONEER MARINER VIKING LUNAR ORBITERS LUNAR COMM	13.25-14.2, 14.4-15.35

Future Operational Comm/Nav Systems

OPERATIONAL CLASS	SPECIFIC APPLICATIONS	1 0-100MHZ	2 100MHZ-3GHZ	3 3GHZ-10GHZ	4 10GHZ-200GHZ	5 10.6μ-0.53μ
POINT-TO-POINT (TRUNK) COMMUNICATIONS	INTELSAT V, VI, ... EUROPEAN COMSAT			•	•	•
	MILITARY DSCS-III, IV,..	•	•	•		
ADVANCED DOMESTIC SATELLITES	INFORMATION NETWORKS ADVANCED TV, TELEPHONE DISTRIBUTION ALASKAN NETWORK DIRECT BROADCAST TV		•		•	
DATA COLLECTION	ADVANCED TIROS, ERTS, ETC. SEARCH AND RESCUE POSITION LOCATION OF MOBILE TRANSMITTERS		•			•
DATA RELAY	TDRS (FOR LOS)					
	TDRS/LOS		•		•	
	TDRS/GROUND				•	
	TDRS/TDRS				•	•
	TDRS (FOR DEEP SPACE)				•	
NAVIGATION/ATC	ADVANCED AERONAUTICAL SERVICES		•			•
	DEFENSE NAVIGATION SATELLITE SYSTEM		•			•
MANNED LOW-ORBIT SPACECRAFT	SPACE SHUTTLE SPACE STATION		•		•	•
DEEP-SPACE/LUNAR COMMUNICATIONS	PIONEER MARINER VIKING LUNAR ORBITERS LUNAR COMM		•		•	•

Probable Future System Frequency Bands

Frequencies associated with applications/ services can be conveniently divided into five bands, a fact which is important in minimizing the amount of lab. equipment (commonality) needed to perform a large number of experiments.

Technical problems anticipated in the development of future systems are summarized in the table below.

OPERATIONAL CLASS	PRINCIPAL BAND	RFI	PROPAGATION	SYSTEMS	SUBSYSTEMS
POINT-TO-POINT COMMUNICATIONS	MILITARY 30HZ-30KHZ 225-400MHZ 7/8GHZ COMMERCIAL 4/6GHZ >11GHZ	TERRESTRIAL NOISE TERRESTRIAL NOISE; GROUND EQUIPMENT SUSCEPTIBILITY TO SAT RADIATION	MULTIPATH AND SCINTILLATION AT UHF ATTENUATION AS A FUNCTION OF WEATHER AT > 11GHZ PHASE COHERENCE OVER WIDE BANDS	FREQUENCY REUSE NEW MULTIPLE ACCESS/MOD METHOD (EG TDM)	SWITCHING AND ROUTING REPEATERS ANTENNA ACQUISITION & TRACKING
ADVANCED DOMESTIC SATELLITES	DIRECT TV BROADCAST TV, TELEPHONE DISTRIBUTION; INFORMATION NETWORKING	NOISE NOISE	>11GHZ PHASE COHERENCE	LARGE NUMBER OF USERS HYBRID MOD METHODS VARIABLE TDM RATES	SWITCHING AND ROUTING SYNCHRONIZATION & REMOTE OSCILLATORS
DATA COLLECTION	100MHZ 3GHZ	NOISE (400MHZ)	MULTIPATH	POSITION LOCATION ACCURACY REAL TIME ACCURATE LOS TRACKING HIGH TRAFFIC DENSITY	DATA COMPRESSION, REDUCTION TECHNIQUES ERROR CORRECTION CODING ON-BOARD PROCESSING REDUCE DATA STORAGE REAL TIME TX REDUCE OVERALL SYSTEM COSTS
DATA RELAY SATELLITES	140MHZ 2GHZ >11GHZ 60 GHZ LASER	140MHZ	>11GHZ 60GHZ LASER	200BPS ⟶ 1GBPS FOR FUTURE TDRS/TDRS LINKS	ACQUISITION AND TRACKING OF LOS CODING/MODULATION
NAVIGATION/ATC	1.5/1.6GHZ	NOISE	MULTIPATH	100,000 USER MULTIPLE ACCESS HIGH POSITION ACCURACY (100' NEAR TERMINALS) FREQUENCY CONSERVATION	IMPROVED RANGING TECHNIQUES (LOW COST) HIGH POWER LINEAR TRANSPONDERS
MANNED LOW-ORBIT SPACECRAFT	2GHZ >11GHZ LASER		TOPSIDE ATMOSPHERE GRAZING REENTRY (PLASMA) BLACKOUT (SHUTTLE)	TDRS TRACKING TERMINAL LANDING (SHUTTLE) HIGH DATA RATE STATION/TDRS LINKS	ON-BOARD PROCESSING
DEEP SPACE/LUNAR COMMUNICATIONS	>11GHZ LASER			ACCURATE TRACKING	

Anticipated Technological Problems

The idea, of course, of all experiments is to obtain data. The first question regarding the data obtained is whether or not there actually will be any. That is, a number of the planned experiment point measurements are rather more in the nature of demonstrations of services or applications. It is important to determine if the activity to be conducted within the CNRL falls in the category of demonstration or experiment. The question is important because different standards should be used to judge the relative merits of one demonstration over another and one experiment over another. Obviously, there will be overlap between demonstration and experiment; no exercise will be entirely one or the other.

A second question regarding data is whether the experiment is feasible, with high confidence, and/or that the equipment might be used for a "fall-back" experiment. This relates to the experiment-specific equipment. Is it needed? Can it be used otherwise?

Timeliness of Comm/Nav Research Laboratory experiments with those planned for unmanned, automated, spaceflight programs was another experiment selection consideration.

PROGRAM	TIMING	EXPERIMENTS
NASA RESEARCH TECHNOLOGY OPERATING PLANS (RTOPS) AND ADVANCED APPLICATIONS FLIGHT EXPERIMENTS (AAFE)	CONTINUING	CONCEPTUAL DESIGNS AND DEVELOPMENT IN GROUND LABORATORIES OF REQUIRED TECHNOLOGICAL SYSTEMS TECHNIQUES AND DEVICES FOR SUBSEQUENT SPACE TEST: ANTENNAS, TRANSMITTERS, RECEIVERS, MODEMS, ON-BOARD PROCESSING COMPONENTS, LASERS, ETC.
NASA/ESRO BALLOON/AIRCRAFT TESTS	FY 72/73	L-BAND RANGING, VOICE AND DATA COMMUNICATIONS UTILIZING A HIGH ALTITUDE BALLOON TO SIMULATE ONE SATELLITE OF AN AIR TRAFFIC CONTROL SYSTEM. 1. PROPAGATION EFFECTS AT L-BAND (1.5/1.6 GHZ) 2. VOICE PERFORMANCE DATA (NBFM, PDM, ETC.) 3. DATA ERROR RATES 4. COMPARISON OF DERIVED RANGE WITH RADAR-DERIVED RANGE 5. OPERATIONAL PROBLEMS
NASA APPLICATION TECHNOLOGY SATELLITES	LAUNCH OF ATS-F IN 1973, ATS-G IN 1975	PERFORMANCE OF DATA COLLECTION, COMMUNICATIONS AND NAVIGATION EXPERIMENTS USING GEOSYNCHRONOUS SATELLITES. ATS-F EXPERIMENTS : 1. POSITION LOCATION AND AIRCRAFT COMMUNICATION EXPERIMENT (PLACE) AT 1.5/1.6GHZ 2. TELEVISION RELAY USING SMALL TERMINALS (TRUST) 3. RFI MEASUREMENTS (6GHZ) 4. MILLIMETER WAVE PROPAGATION (20 AND 30 GHZ) 5. DATA RELAY (WITH NIMBUS)
NASA SMALL APPLICATION SATELLITES (SATS)	ENGINEERING MODEL PLANNED FOR COMPLETION IN CY-73	SPACECRAFT DESIGNED TO CARRY OUT SPECIALIZED EXPERIMENTS IN THE APPLICATIONS DISCIPLINES. WILL PROVIDE AN IN-ORBIT ENVIRONMENTAL AND SYSTEMATIC TEST CAPABILITY FOR CRITICALLY NEEDED APPLICATIONS-ORIENTED INSTRUMENTATION, IN A QUICK-REACTION, LOW-COST BASIS, FOR ERTS, NIMBUS, ATS, NAVSATS, ETC.
DOD's SPACE EXPERIMENTS SUPPORT PROGRAM (SESP)	PERIODIC; LATEST LAUNCH (9 POLAR-ORBIT SATELLITES) AUGUST 6, 1971	PROVIDES FOR ORBITING OF SPACE RESEARCH PROJECTS NOT AUTHORIZED THEIR OWN BOOSTERS. ANY MILITARY OR OTHER GOVERNMENT AGENCY CAN SPONSOR A PAYLOAD, BUT IT MUST HAVE A POTENTIAL MILITARY VALUE. ONE OR TWO EXPERIMENTS (USUALLY) PER SATELLITE. THE SATELLITES JUST LAUNCHED WILL MEASURE: 1. ATMOSPHERIC CONDITIONS 2. GEOPHYSICAL PHENOMENA 3. PRECISION RADAR CALIBRATION OF TARGETS
COMSAT's EXPERIMENTAL SATELLITE	PLANNED LAUNCH IN 1974	FULLY-STABILIZED DELTA-LAUNCHED SPACECRAFT TO TEST FREQUENCY REUSE BY MEANS OF SPOT BEAMS, (1-2^{o}) ON-BOARD SWITCHING, AND PROPAGATION EXPERIMENTS AT 12/13GHZ AND 20/30GHZ.
CANADA's COMMUNICATION TECHNOLOGY SATELLITE	PLANNED LAUNCH IN 1973	THREE-AXIS STABILIZED SYNCHRONOUS-ORBIT SATELLITE TO SPACE-QUALIFY A NUMBER OF DEVICES AND TECHNIQUES FOR NORTH AMERICAN DOMESTIC SATELLITE SERVICES: 1. COLOR TV AND AUDIO BROADCASTS TO SMALL LOW-COST EARTH TERMINALS 2. TWO-WAY VOICE COMMUNICATIONS 3. WIDE-BAND DATA TRANSMISSION EXPERIMENTS 4. DATA RELAY EXPERIMENTS 5. TEST OF A 50% EFFICIENCY TWT, 200W, 12GHZ 6. LONG-TERM STATISTICAL PROPAGATION TESTS

Current Comm/Nav Experimental Programs

As a practical matter, the criteria of having each experiment relate directly to some particular anticipated system is probably as good a filter as any.

For planning purposes, the limits of the Shuttle Orbiter are assumed to be from 100 to 470 nautical miles in altitude and from 0 to 90 degrees inclination. The table below compares the relative advantages of performing an experiment in synchronous and in low altitude orbits, and is indicative of the benefits of low orbit experimentation. Experiment duration depends on the measurements required. Some experiments can be completed on one 7 day Sortie mission; others will require several missions to collect all needed data.

CHARACTERISTIC	SYNCHRONOUS ORBIT (S)	LOW-ORBIT (L)	PREFERABLE MODE
ALTITUDE			
1. INSTANTANEOUS VIEW	1/3 THE EARTH	2800 MI. DIAMETER	S
2. VIEWING TIME	CONTINUOUS	A MAXIMUM OF 12 MINUTES, 100 MINUTE PERIOD	S
3. TRANSMIT POWER	HIGH BECAUSE OF DISTANCE	30-40 DB LOWER	L
4. RECEIVED SIGNAL LEVELS	LOW BECAUSE OF DISTANCE	30-40 DB HIGHER	L
5. ANTENNA RESOLUTION	LOW BECAUSE OF DISTANCE	80 TIMES BETTER	L
6. EMI	HIGH, BECAUSE OF LARGE VIEWING AREA	LOW BECAUSE OF ANTENNA DISCRIMINATION	L
7. OPERATION FROM WITHIN IONOSPHERE	NO	YES, REQUIRED FOR ELF VLF AND DUCTING EXPERIMENTS	L
8. COST POUND IN ORBIT	HIGH	LOW, BECAUSE OF ORBIT AND BECAUSE OF REUSABLE SHUTTLE	L
9. TRANSFER OF EXPERIMENTAL DATA TO GROUND	HIGH SPACECRAFT ERP REQUIRED	RELATIVELY LOW ERP	L
10. INTERFERENCE TO TERRESTRIAL SYSTEMS	MEDIUM	LOW, BECAUSE OF ANTENNA	L
SATELLITE MOTION			
1. GLOBAL COVERAGE	NO	YES, UP TO ABOUT 65° LAT.	L
2. DOPPLER SHIFT	NOT APPRECIABLE	MUST OFTEN BE CORRECTED FOR	S
3. STRIP-SCANNING OF EARTH AREAS	COARSE	SIMPLE DUE TO ANTENNAS AND SPACECRAFT MOTION	L
4. MEASUREMENTS WITH VARIABLE ELEVATION ANGLE	REQUIRES NUMEROUS GROUND EQUIPMENTS OR CONSIDERABLE EQUIPMENT MOVEMENT	SIMPLE BECAUSE OF SPACECRAFT MOTION	L
OPERATIONAL			
1. SIMULATION OF LOW-ORBIT USERS	NOT FEASIBLE	IDEAL	L
2. MANEUVERABLE ATTITUDE	DIFFICULT	SIMPLE	L
3. CAPABILITY TO DOCK OR APPROACH OTHER SPACECRAFT	VERY DIFFICULT	INHERENT IN SHUTTLE DESIGN	L
4. SIMULATION OF OPERATIONAL SYNCH. SATELLITES	IDEAL	ONLY PARTIAL	S
5. EXPERIMENTAL LEAD TIME	TIME BETWEEN EXPERIMENT SELECTION AND FLIGHT IS LONG (3-4 YRS.)	QUICKER REACTION FLIGHT TEST CAPABILITY	L

Relative Advantages of Synchronous and Low Orbit Communications/Navigation Experimentation

The application of man usefulness criteria was more difficult. It is apparent

- MANUAL TUNING OF TRANSMITTERS AND RECEIVERS; OPERATION OF EXPERIMENT SUPPORT EQUIPMENT; CONTROL OF DATA COLLECTING AND RECORDING DEVICES
- MANUAL OPERATION OF ANTENNA POINTING EQUIPMENT
- ASSEMBLY OF LARGE ANTENNA STRUCTURES (EVA OPERATION)
- EXPERIMENT STRUCTURING/PLANNING/EXECUTION, INCLUDING REQUIRED ITERATIONS, BASED ON REVIEW OF GROUND TRANSMITTED DATA OR OBSERVABLES
- DATA PROCESSING/REDUCTION/SYNTHESIS, INCLUDING REPROGRAMMING OF EXPERIMENTS IN NEAR-REAL TIME
- MAINTENANCE, MALFUNCTION ISOLATION, AND REPAIR
- DATA QUALITY CONTROL THROUGH INTERIM AND SUBSEQUENT (TO DATA TAKING) EVALUATION
- SENSOR/EXPERIMENT EQUIPMENT RESEARCH AND DEVELOPMENT FOR SUBSEQUENT UNMANNED OPERATION
- RESPONSE TO UNPROGRAMMED EVENTS AND EMERGENCIES

Types of Activities Expected of Payload Experimenter Crew Personnel on Comm/Nav Research Laboratory Missions

that the principal advantage of a manned laboratory will accrue from the fact that a man, working with mechanically interchangeable components and a limited number of fixed equipment configurations, each designed for a particular frequency band, can perform a large number of experiments, with the only practical limit being the crew time available for the tests.

Inherent in the combination of manned and low altitude missions in earth orbit is that the development of technology and hardware for operational systems will be advanced in time over conventional testing with unmanned, single purpose spacecraft.

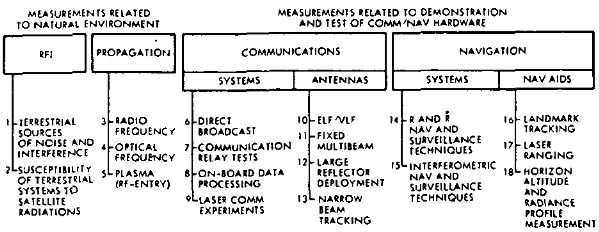
Experiment Classes

Using the above criteria for experiment selection it was possible to solicit from government, industry, university, and international sources, a large number of point experiments for possible performance in a CNRL in future Space Shuttle and, possibly later, Space Station missions. As a direct result of these efforts, a total of 114 experiment suggestions were received. The organizations contributing these candidate experiments, and the number submitted by each group, are presented below.

ORGANIZATION	NO. OF EXPERIMENTS
GOVERNMENT (51) ≈45 percent	
Goddard Space Flight Center	10
Marshall Space Flight Center	1
Langley Space Flight Center	1
Manned Spacecraft Center	5
Langley Space Flight Center/North American Rockwell	1
Environmental Science Services Administration	2
Institute for Telecommunication Sciences	16
Mitre Corporation	1
January - 1971 Blue Book, Volume 5, Comm/Nav	13
National Oceanic and Atmospheric Administration	1
INDUSTRY (54) ≈47 percent	
TRW Systems Group	25
McDonnell Douglas Astronautics Company	3
Comsat Corporation	11
Bell Laboratories	4
Honeywell	1
Raytheon/Wright-Patterson Air Force Base	1
Hughes Aircraft Corporation	2
General Electric Space Systems	1
Westinghouse Space Systems	2
Radiation Systems	1
National Scientific Laboratories	1
Fairchild Hiller Corporation	1
IBM	1
UNIVERSITY (8) ≈7 percent	
University of Illinois	2
University of Pennsylvania	1
University of Houston	3
Massachusetts Institute of Technology	1
Stanford University	1
INTERNATIONAL SOURCES (1)≈1 percent	
Hawker-Siddeley Dynamics, England	1
TOTAL	114

Source of Candidate Experiments

Detailed sorting and screening of experiment suggestions resulted in placement of each experiment, that met the selection criteria, into one or more of the following investigation areas: electromagnetic interference, propagation phenomena, communications systems demonstration and component testing, navigation systems demonstration, and checkout of navigation aids. Within this investigation area framework, 18 experiment classes were identified.



Class Grouping of Candidate Experiments. Each Class Described in Volume II.

Page 13 lists the 18 experiment classes with their research objectives.

Experiment Class Time Phasing

The initial or Early Comm/Nav Research Laboratory is associated with seven day Shuttle Orbiter sortie flights in the 1980 to 1985 time period. About 1985 this Early laboratory will probably expand into Growth versions where these growth versions would take various forms. At the end of the 1980 decade an all-purpose, or Total, Comm/Nav Research Laboratory is envisioned. This total laboratory may be attached to the Space Station, be outfitted for two to ten year usefulness, and include the equipment needed to conduct all research across the entire range of experiment classes.

Where the Early laboratory may accommodate four to seven experiment classes, and the Growth version may include up to 12 experiment classes, the Total laboratory will be capable of research in all 18 experiment classes. Of course, over the time period between now and start of Space Shuttle missions these 18 Experiment Classes may undergo significant new alignment.

Using the basic criteria of usefulness, timeliness, cost effectiveness, advantages for crew participation, ability to accomplish experiment objectives on short duration missions, and expected commonality of equipment, the 18 experiment classes were subjected to a quantitative analysis for priority rating and assignment to Early, Growth, and Total laboratory flights. Results of this exercise indicated that, for purposes of laboratory configuration design and equipment layout and mission planning, the following could be representative of experiment class placement:

Early Lab (1980-1985 Missions) Experiment Classes

- Terrestrial sources of noise and interference
- Radio frequency propagation
- Communication relay
- Laser communication
- Fixed multibeam antenna
- Interferometric navigation and surveillance techniques
- Landmark tracking

Growth Lab (1985-1990 Missions) Experiment Classes

Above Early Lab Experiment classes plus

- Susceptibility of terrestrial systems to satellite radiations
- On-board data processing
- Range and rage rate navigation and surveillance techniques
- Horizon altitude and radiance profile measurement
- Narrow beam tracking
- Plasma Prop.

Total Lab (1990 Missions) Experiment Classes

Above Early and Growth Lab Experiment classes plus

- Laser ranging
- Optical propagation
- Direct broadcast
- Large reflector deployment
- ELF/VLF antenna

Experiment Class Time Phasing

EXPERIMENT CLASS	MAJOR OBJECTIVES OR MEASUREMENTS
1. Terrestrial Sources of Noise and Interference	Map terrestrial noise and interference sources in operational and projected frequency bands of interest.
2. Susceptibility of Terrestrial Systems to Satellite Radiations	Evaluate the magnitude of the interference experienced by terrestrial communication systems from transmissions by orbiting spacecraft.
3. RF Propagation	Investigate RF propagation effects including multipath, scintillation, and Faraday rotation.
4. Optical Propagation	Extend the knowledge of optical wavelength propagation phenomena in the atmosphere and free space.
5. Plasma Propagation	Investigate feasibility of transmitting signals from a re-entering vehicle via a relay satellite, instead of directly to the ground.
6. Direct Broadcast	Demonstrate feasibility of TV transmission from a satellite directly to the home viewer.
7. Communication Relay Tests	Evaluate equipment, procedures, and techniques related to communications via a data relay satellite (TDRS).
8. On-Board Data Processing	Demonstrates techniques to reduce interference, alleviate multipath, provide direct user control, and improve flexibility.
9. Laser Communications	Refine and extend laser technology space in applications at various optical frequencies.
10. ELF/VLF Antenna	Improve knowledge of radiation and propagation phenomena in the ionosphere at ELF/VLF frequencies.
11. Fixed Multibeam Antenna	Demonstrate and evaluate relative performance of competing multiple beam concepts in a space environment for: frequency reuse, polarization isolation, and beam and side lobe control.
12. Large Deployable Reflectors	Evaluate the deployment mechanism/sequence and performance of large deployable reflectors in space.
13. Narrow Beam Tracking	Measure and optimize performance of ultra-narrow beam antennas for space-to-space communication applications.
14. Range and Range Rate Navigation and Surveillance	Demonstrate and evaluate range and range rate measuring techniques for future terrestrial navigation, surveillance, and search/rescue systems.
15. Interferometric Navigation and Surveillance	Demonstrate the line-of-sight measurement accuracy of a long baseline spacecraft receiving interferometer as a candidate for future navigation or surveillance systems.
16. Landmark Tracking	Determine the feasibility and accuracy of autonomous navigation using unknown earth landmarks.
17. Laser Ranging	Evaluate utility and accuracy of an on-board laser ranging system for application with cooperative and uncooperative targets.
18. Horizon Altitude and Radiance Profile Measurements	Measure the spectral radiance profile of the earth, and especially the horizons, for application to earth-pointing systems.

Candidate Comm/Nav Experiment Classes and Their Objectives

The selected Early laboratory experiments are well suited for low orbit missions. The measurement of terrestrial RFI, for example, is enhanced because of high receiver sensitivity (proximity to earth), the ability to localize sources of interference, and the capability to perform sequential area mapping on a global basis.

Similar remarks pertain to the RF propagation experiment where multi-path phenomena can be measured over varying terrains and elevation angles.

Laser experiments are expedited by the presence of man who can align, adjust, change filters, evaluate performance, etc. and, thereby, perform a large number of related experiments not practical in automated spacecraft.

The equipment required for the performance of these experiments could be used for other experiments with minor modification. For example, the Landmark Tracking experiments can be conveniently performed using portions of the Laser Communications equipment, such as the telescope optical mount. This equipment could also be used for Laser Ranging Tests.

Experiment Equipment Instrumentation (Tasks 2 and 3)

Fundamentally the experiment equipment/instrumentation to conduct communication/navigation research on-board a manned orbital laboratory includes: antennas, receivers, transmitters, measurement display consoles, control panels, and general support devices.

Functional Requirements

Functional requirements for each of the 18 experiment classes were evaluated to identify the major performance characteristics. The requirements pertain to specific values for the functions and categories shown below.

FUNCTION	RATIONALE CONSIDERATION
FREQUENCY SELECTION	• USER REQUIREMENTS • EXISTING ASSIGNMENTS • MAXIMIZE/MINIMIZE EFFECT • EQUIPMENT AVAILABILITY
TRANSMITTER POWER	• LINK BUDGET ANALYSIS • INTERFERENCE
ANTENNA GAIN	• BEAM PATTERN • EQUIPMENT AVAILABILITY
RECORD/DISPLAY	• FREQUENCY/SPECTRUM OF DATA • DATA FORMAT-ANALOG/DIGITAL • DATA ACCURACY • TOTAL AMOUNT OF DATA • PROCESSING TECHNIQUES
GENERAL SUPPORT EQUIPMENT	• PREVIOUS EXPERIENCE

Functional Requirements Rationale

CATEGORIES	CHARACTERISTICS
• LINK CONFIGURATION	• SPACE TO EARTH, SPACE TO SPACE, EARTH TO SPACE
• TRANSMISSION	• FREQUENCY, BANDWIDTH, MODES, POWER, MODULATION
• RECEPTION	• FREQUENCY, BANDWIDTH, MODES, THRESHOLD, DYNAMIC RANGE, DEMODULATOR
• ANTENNA	• FREQUENCY, POLARIZATION, GAIN CONTROL
• MEASUREMENT AND DISPLAY	• TYPE, ACCURACY, BANDWIDTH, FREQUENCY, DYNAMIC RANGE, OUTPUT DATA
• GENERAL SUPPORT EQUIPMENT	• CALIBRATION, MONITOR/MAINTENANCE, CONTROL, COMMUNICATIONS

Definition of Functional Requirements

Equipment Lists

The output of the functional requirements analysis was individual lists of equipment identifying quantity, function/technical description, mass properties and power consumption for each of the 18 experiment classes. A representative for the Terrestrial Sources of Noise and Interference experiment class is shown. Similiar lists were compiled for the remainder of the experiments.

EXPERIMENT: LASER COMMUNICATIONS

EXPERIMENT: FIXED MULTIBEAM ANTENNA

EQUIPMENT LISTING

EXPERIMENT: TERRESTRIAL NOISE

ITEM	Qty	FUNCTION	TECHNICAL DESCRIPTION	Commercial Equivalent Item	SIZE (INCHES)	Weight (LBS)	Power (W)
ANTENNA	1	Signal Collection	Dual Orthogonally Polarized, Dual Beamwidth, Log Periodic VHF-UHF Assembly	TRW or RF Systems, Inc.	60 x 60	38	
RELAY	2	Polarization Selection	3-Position, Coaxial, 50. Ohm for, Vert, Horiz, and EMI Calibration		2-1/4 x 1-3/4 x 1	0.4	
ATTENUATOR	4	Dynamic Range Adj.	0 - 60 dB, 50. Ohms, Remote Electrical Control, Digital Readout of Value, Manual Over-ride	Merrimac	3 x 3 x 4		
RECEIVER	4*	Signal Selection	100 - 1000 MHz, Sweep Mode or Tunable	Singer NM37-57 (Stoddard)	16-3/4 x 18-1/2 x 8-3		
DISPLAY	2	RF Density & Waveforms	Single Design Functions As Power Spectral Density Display for Quicklook & as Modulation Monitor	Tektronic or H.P.	8 x 19 x 15		
SCAN PROG. GENERATOR	3	Directs Sweep Receiver	Generates Digital Control Signals for Receiver and Supplies Digital Readout of Frequency & Level	Singer P-7 (Stoddard)			
CALIBRATION UNIT	2	Provides Known Power Levels	5-Spot Frequencies, Known, Incrementally Controllable Power Level for Standardization	TRW			
RECORDER INTERFACE	2	Data Formatting	Accumulates Pre/Post Amble, Clocks Start Of Each Test & Data Acquisition	TRW			
RELAY	2	Input Receiver/Spare	2-Position, Coaxial Relay, 50 Ohm, Selects Regular or Spare Receiver for Each Channel				
RELAY	2	Output Receiver/Spare	2-Position, Coaxial Relay, 50 Ohm, Selects Regular or Spare Receiver Output for Each Channel				
POWER CONDITIONER	2	Regulation, Filtering	Generates Bus Voltages for All Electroni... for				

Experiment-Unique Equipment Lists

Predicated on the selected payloads for various Comm/Nav Research Laboratories (Early, Growth, Total) these lists were analyzed to identify common equipment functions compatible with performance requirements. "Common-Core" and "experiment unique" equipment lists were synthesized. Common core designates those items of equipment characterized by similar performance characteristics which may be shared by the several experiments utilizing them, providing the operational usage requirements do not conflict. Clocks, tape recorders, oscilloscopes, spectrum analyzers and digital voltmeters are examples of common core equipment. The experiment-unique category includes equipment which is peculiar to a single experiment. Examples are sensors, receivers, transmitters, optics, and antennas.

These lists were used to initiate equipment conceptual designs which were translated to interior layouts for selected laboratory configurations.

Equipment Commonality

Criteria for assessing the commonality of candidate equipment fall into two types: (1) considerations exclusive of usage, and (2) mission dependent considerations. Under considerations exclusive of usage, the criteria are:

- Similarity of functional characteristics
- Similarity of equipment performance characteristics
- Complexity (is it worth sharing?)
- Redundancy (is redundancy desirable?)

In regard to mission dependent considerations, the commonality criteria thought to be of major importance are:

- Experiment complement for specified mission
- Time phasing of experiment operations
- Operational convenience (minimize reconfiguration, recalibration, flight experimenter fatigue)

Utilizing the equipment lists for the 18 experiment classes, consolidated groups were developed. For example, an inclusive table of antennas required to support all experiment classes was synthesized. The essential performance characteristics for each type of antenna, such as gain, polarization, and frequency bands were also identified. The remaining four types of equipment were subjected to a similar reorganization.

The next step was to apply the commonality criteria. The preliminary results of this analysis reveal the limits which may be approached in minimizing the numbers of equipment required to support a Comm/Nav Research Laboratory Program.

	Without Commonality	With Commonality	Reduction (Percent)
Receivers	29	12	59
Transmitters	20	8	60
Antennas	22	8	64
Optics	39	16	59
General Support Equipment	481	72	85

Total Number of Discrete Items of Hardware

The conclusions which were drawn from the commonality analysis are:

1. The degree of commonality varies with the experiment complement.
2. Operating frequency is a major factor in determining equipment commonality.
3. Commonality has many additional implications (reliability, orbit, duty cycle, etc.) which must be evaluated before a final laboratory configuration can be proposed.

There will be an increasing tendency toward equipment commonality as the CNRL program evolves. This desirable trend is attributed to the increasing number of experiments which will be accommodated by the laboratory as well as the experimenter crew members' ability to reconfigure experiments during a mission.

Commercial Equipment

There are two paramount goals to be achieved in the use of experiment equipment/instrumentation. They are:

- Maximum utilization and growth capability through the concept of modular design. In particular, electronic gear lends itself to modularization.
- Minimum unit cost, wherever possible, through the use of commercial equipment/instruments and competitive availability through multiple suppliers. The paragraphs below are addressed to the latter goal — use of commercial equipment.

Experiment common-core equipment items were examined to determine if their function and performance was similar to commercially available laboratory equipments. Where the answer was yes, the commercial equipment was subjected to a review of its operational and packaging characteristics in terms of:

1. Safety to the crew and other laboratory equipment.

2. Size, materials
3. Mounting method
4. Thermal control technique
5. Connector panels } placement, number, type
6. Control panels } placement, number, type
7. Maintenance needs
8. Self-check requirements
9. Electromagnetic interference problems
10. Comm/Nav Research Laboratory physical environment
11. Electric power demands

The CNRL physical environmental (No. 10, above) pertains to load factors, temperature, pressure, acoustics, vibration, RFI, and humidity.

It was appropriate to ask whether commercially available (in contrast to space-qualified) hardware might be suitable or adaptable for use in a CNRL. Four questions appear to dominate the feasibility of using commercial hardware:

1. Is it safe to put into a habitable, pressurized, compartment?
2. It is suitable for use by man in a zero-g environment. Will it still perform its intended function?
3. Would it survive the Space Shuttle launch, orbit, deboost, entry, and landing phases of the mission?
4. On the basis that some equipment modification is needed to comply with 1, 2, 3, what is the development time and cost to adapt the equipment to meet operational needs and safety standards?

Of some 25 quality vendors contacted, 22 replies were returned containing comments as to the use of commercial equipment in manned space missions, and 8 of these 22 replies included detailed information on the suitability of their hardware to meeting environmental criteria and safety standards.

No reply advocated direct use of commercial hardware without modification. The factors which concerned the hardware suppliers the most were modifications to their equipment to cope with: safety, outgassing, flammability, load factors, vibration, temperature, RFI, and pressure. No actual dollars were given, but most replies indicated some cost impact to modify their design(s). Material (outgassing and flammability) is a problem area even though most high-quality companies producing spectrum analyzers, oscilloscopes, digital voltmeters and similar equipment are now using good materials in their components, insulation, and packaging structure. But the biggest problem seemed to be the physical design changes needed to meet safety standards in terms of elimination of cover glass over dials, rounding of corners, recessing of knobs and switches, and substitution of some thermal control device for fans.

The designs and functions of present commercial equipment should be the baseline of discussions of the applicability, shortcoming, and recommendations with commercial equipment manufacturers. Certain assumptions will have to be made to form a basis for problem definition and solution. Such areas as environment, safety, number of units involved in a typical purchase, and lead time required are areas where hard data is not yet available. If cost can be related to equipment modification and redesign (but keeping the function the same), then this correlation may possibly be useful in establishing criteria for an industry specification for future commercial hardware for manned space laboratories.

The impact on commercial producers, if NASA purchases all of their common core equipment to a Standard Commercial Specification, will not be ignored.

The key is getting a Standard Commercial Equipment Specification that is below the high reliability number associated with long duration, unmanned, spacecraft flight, but still suited to safety standards of a manned space laboratory. If this is done, payload costs may be lowered.

Systems and Operations Analysis (Task 4)

A manned Earth orbital program of Comm/Nav Research has the following objectives:

- Perform useful experiments in (1) natural environment measurements as related to RFI and propagation and (2) measurements to demonstrate and test Comm/Nav hardware related to future operational systems.
- Provide scientifically responsive space laboratories that are accessible, versatile, economical, and sensitive to research requirements.
- Provide programmatically flexible laboratories in terms of funding, schedule, and priorities.
- Complement and supplement related programs where unmanned missions, aircraft flights, and ground based research are employed in Comm/Nav research.

The study derived experiment classes and the laboratory configurations are the suggested starting points toward meeting the above objectives. Assuming that Comm/Nav manned laboratories do evolve to conduct space research, the success of the program will depend to some degree on the care given to mission planning. This element is discussed briefly--concentrating on the aspects of flight schedules, crew size/skills, timelines, data requirements, and orbit considerations of the Early Laboratory.

Early Laboratory — Typical Flight Schedule

The key features of a possible flight schedule for Early Laboratory missions for six (of the seven) experiment classes selected for the Early Laboratory shows modest changes in crew involvement, geographic coverage and experiment unique equipment as the flight schedule proceeds in easy steps or modifications until Early Laboratory objectives are achieved.

It is assumed that data derived in some of the early experiments may contribute to the definition of operational systems. Thus, the chart above (Flight Schedule) shows a series of mission modifications, say eight, where man's participation is gradually changed. The natural consequence of this, plus the desire to expand experiment coverage, will lead to increased use of automated equipment.

Expanding the geographic coverage is an important element of experiment measurements. For example, the low inclination orbit might prove to be an obstacle in establishing the propagation of RF energy through snow. An elliptical orbit could provide more station contact time and thereby enhance the experiment results. This improved temporal coverage could become a necessary element in achieving certain experiment objectives.

Experiment equipment changes could be made as the measurement sequence in each experiment class is revised and updated. A gradual evolution in equipment complexity and capability rather than "block changes" is a primary element in the schedule structure. The Flight Schedule Chart suggests eight equipment modifications, but this is arbitrary at this point. An average of two flights

MAN HIGHLY INVOLVED | MAN SUPERVISED | SEMI-AUTOMATED MAN MONITORED → INCREASING EQUIPMENT COMPLEXITY

Payload		EXPERIMENT DESCRIPTOR	MOD 1	MOD 2	MOD 3	MOD 4	MOD 5	MOD 6	MOD 7	MOD 8
PAYLOAD "A"	1A	VHF - UHF	•							
	3A	VHF - UHF	•							
	9A	LOW EARTH ORBIT TO GROUND	•	•						
	11A	RECEIVE ONLY-SINGLE BEAM	•	•						
	15A	RECEIVE ONLY-SINGLE BASELINE	•	•						
	16A	SHARED OPTICS-VISIBLE SPECTRUM	•	•						
PAYLOAD "B"	1B	SHF ONLY		•	•					
	3B	SHF ONLY		•	•					
	9B	LOW EARTH ORBIT TO AIRCRAFT			•	•				
	11B	TRANSMIT ONLY-1 BEAM			•	•	•			
	15B	RECEIVE ONLY-DUAL BASELINE			•	•	•	•		
	16B	SHARED OPTICS-IR SPECTRUM			•	•	•	•	•	
PAYLOAD "C"	1C	VHF - SHF				•	•	•	•	•
	3C	VHF - SHF				•	•	•	•	•
	9C	LOW EARTH ORBIT TO SATELLITE					•	•	•	•
	11C	MULTIPLE TXPONDER-MULTIPLE BEAM						•	•	•
	15C	TRANSMIT ONLY-DUAL BASELINE							•	•
	16C	DEDICATED OPTICS								•

↓ INCREASING EXPERIMENT CAPABILITY

NOTE: APPROXIMATELY 2 FLIGHTS/MOD RECOMMENDED 2-3 FLIGHTS PER YEAR

→ TIME

200 MILE CIRCULAR 30° INCLINATION | 100 x 600 MILE ELLIPTICAL 50° INCLINATION | 300 MILE CIRCULAR 90° INCLINATION → INCREASING GEOGRAPHIC AND TEMPORAL COVERAGE

Early Laboratory — Typical Flight Schedule

per modification may be needed to meet experiment objectives. Two to three Comm/Nav Research Laboratory flights per year are recommended but this, of course, depends on funding constraints and Shuttle Orbiter availability.

The NASA document titled Updated NASA Mission Model dated 6 June 1972 from the AAD/Deputy Associated Administrator provides a planning guide for NASA and for those contractors supporting the Agency's projects. It indicates a NASA Mission Model extending from 1973 through 1990. For Communications and Navigation this model shows: one Sortie Comm/Nav experiment flight in each of the calendar years 1979, 1980, 1983, 1984, 1987 and 1990; one Comm/Nav Sortie Laboratory flight in each of the calendar years 1981, 1982, 1985, and 1989; and Comm/Nav Space Station RAM Laboratory flights of two to three months mission duration in calendar years 1986 and 1988.

Thus, this mission model, which suggests one Comm/Nav mission a year (1979 through 1990), is in slight variance with this Study's recommendation of two to three missions per year. However, continued mission modeling work and further Comm/Nav analysis of the experimental needs to fill technology gaps may result in revisions to the NASA model or to the recommendation.

There are various techniques available for dealing with the limitation of experiment time/data associated with the Sortie mission duration. One technique is to collapse the experiment "class" to a "point" experiment. This involves reducing the class scope in such areas as frequency coverage, operating modes, and performance.

The objectives of a point experiment can obviously be limited to a set which is compatible with a seven day mission. Or the laboratory equipment could be expanded (or duplicated) to focus on multiple sets of data. Thus, the experiment class would really be implemented as a set of point experiments. Alternatively, it is reasonable to recognize the shortcomings of a limited flight duration and plan for multiple flights.

The terrestrial noise experiment involves collecting data over a wide range of frequencies. Terrestrial noise is known to have seasonal variations. It is highly correlated with the activities of man and hence it will constantly vary. Any given set of data will be perishable at some detail level and new data will always be needed. This experiment will eventually lead into an operational monitoring system after some number (N) of Sortie flights.

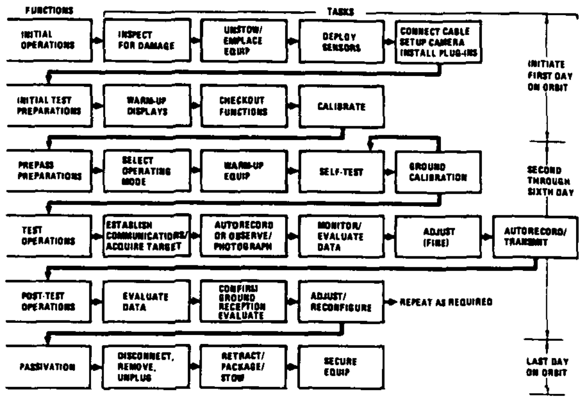
The fixed multibeam experiment is postulated as one which may involve difficulty in establishing satisfactory space-ground coordination. Multiple flights could be required to achieve experiment objectives.

The laser communication experiment could also have space-ground operational problems (cloud cover over the ground station). Further, the experiment involves multiple operating modes. Initially a one way space-ground link would be established. This would lead to a more complex space-aircraft link and finally to a laboratory-satellite link.

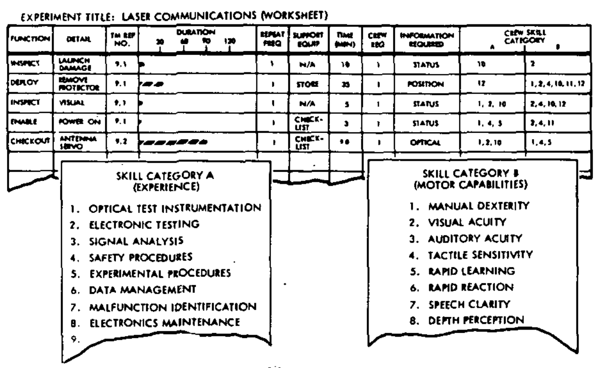
Crew Size/Skills – Early Laboratory

It is assumed the Early Laboratory missions will involve four Shuttle Orbiter / Laboratory crew members - commander and copilot to handle Orbiter flight duties and two mission/payload specialists to conduct Comm/Nav experiments.

Experiment functional flows and crew skill analysis charts were constructed to determine the crew scope of work and the crew experience/training needed to perform the seven selected Early Laboratory experiments.



Typical Experiment Function Flow



Crew Skill Analysis

Some of the operational phases and their associated tasks are shown above for a typical experiment. Certain experiments may have automated or pre-programmed phases. There are no tasks shown for maintenance, analysis, reconfiguration, written log entries, and computation. The scope of this analysis was necessarily limited to the broader aspects of crew activities.

In order to adequately define the training and skill demands which the selected experiments would place upon the crew, each Early Laboratory candidate experiment was analyzed in some detail. A logical succession of events was structured for (as example) the laser communication experiment. Each operation was analyzed for various features, including crew skill.

Two categories of crew skills were deemed important. First, the category A data indicated prior experience or knowledge which might be applicable. The category B entry identifies specific motor skills which will be required to carry out the task. These data are still preliminary and have not been fully analyzed or correlated.

Mission Timelines

A preliminary Sortie mission timeline was computer run for the above 2+2 crew for the 7 Experiment Classes on Early lab missions. It was assumed the commander and copilot were not available to participate in experiment operations. The first day of the mission will include launch, to-orbit flight, on-orbit positioning and checkout of the Orbiter and laboratory equipment. The seventh day is assumed to include Orbiter, conditioning for return, laboratory shut-down, de-orbit, Earth entry, landing, and on the ground operations. Therefore, experiment conduct is performed for five of the seven mission days. This gives each experiment crew member a possible 5 x 24 = 120 hours. The NASA standard times for eating, sleeping, hygiene, and attendant to laboratory subsystem operations were deducted. These totaled approximately 70 hours for each man for the five days, leaving (120-70) 50 hours for experiment conduct. Further assumptions for this timeline were:

- Experiment data involving ground viewing and communications were restricted to continental United States.
- The Data Relay Satellite placement was assumed to be 145°W and 15°W, as reported in the latest NASA Headquarters planning documents.
- Orbit altitude - 260 nautical miles, circular, 35 degrees inclination.
- The ground network supporting the mission was assumed to consist of the following ground stations:

Goldstone, California	(GLD)
Guymas, Mexico	(GUY)
Corpus Christi, Texas	(TEX)
Merritt Island, Florida	(MIL)
Goddard Space Flight Center	(GSFC)
Bermuda Island	(BDA)
Grand Canary Islands	(CYI)
Ascension Island	(ACN)
Madrid, Spain	(MAD)
Carnarvon, Australia	(CRO)
Honeysuckle Crreek, Australia	(HSK)
Guam Island	(GWM)
Oahu Island, Hawaii	(HAW)
Santiago, Chile	(SAN)

- Single ground station for data dump.
- While ground coverage is shown for the total ground network (indicated by AOS-LOS Blocks on the timeline sheets) operations were assumed to occur over only those ground stations having acquisition elevation angles greater than 20 degrees. This approach results in a very conservative assessment of experiment operation opportunities.
- Arbitrary assignment of experiment responsibility; that is, experimenter no. 1 is assigned three experiment classes, experimenter no. 2 is assigned four experiment classes.
- Experiment priorities - The establishment of relative priorities between the seven experiments was required for scheduling of the mission timeline. These priorities were assumed to be the following:

Priority	No.	Title
1	1	Terrestrial Sources
2	3	RF Propagation
3	11	Multi-Beam Antenna
4	9	Laser Communications
5	7	Communication Relay
6	15	Interferometer Navigation
7	16	Landmark Tracking

- Experiment targets and operations -

Exp. No.	Target and Operations
1*	Operates for five passes (minimum) over CONUS.
3*	Operates once for set-up over CONUS then switches to automatic mode for periodic manned operation throughout the mission.
7	Initially operates over Honeysuckle with DRSS, then switches mode for acquisition, handover, and LOS operations throughout mission. This experiment is assumed to be operable with Space Shuttle in <u>any</u> orientation.
9	Operates once per day over Goldstone, California.
11	Operates four times over Texas, on one day only.
15	Operates three passes over KSC, each day throughout mission.
16	Operates over ground stations (Guam and Hawaii primary, MIL and CRO secondary) as often as possible

* These experiments (Nos. 1 and 3) use the same antenna. It was assumed that they could operate in parallel.

Analysis of the mission timeline showed that each experimenter would be occupied about 35 of his 50 hours allocated in the conduct of his experiment class measurements. It is certain that contingency items and experiment replanning on-orbit could erode into the "excess" 15 hours.

Even though each man had his own program to conduct on his assigned experiment classes, there were instances where one man was needed to assist the other in order to perform some activity.

Two key conclusions arose from this timeline: (1) the seven experiment classes represent just about the full utilization of the two crew members' time. Additional experiment classes could be added by increasing the standard work day from 8 to 10 or 12 hours for one or both experimenters and (2) the space-ground contact time for some experiments was extremely small (1-6 minutes during 2-3 contacts per day for laser communications experiment) and should be improved.

Orbital Considerations

To establish the worth of Comm/Nav research data using a Space Shuttle supported manned laboratory, information is needed over a wide range of geographic locations and seasonal variations. In formulating plans for Comm/Nav research flights, two major constraints must be considered:

1. Orbital parameters, especially altitude and inclination, as they influence the Earth coverage, and as they are attainable by Space Shuttle capability
2. The requirements imposed on the laboratory and ground stations that apply to data management, location of ground facilities or sources of information, launch operations, and mission duration (fixed at 7-days for Early Laboratory missions).

Operation of four of the five Early Lab RF experiments is predicated upon an RF communication link between the laboratory and a terrestrial station or source, the exception being the communication relay experiment

where the link is with a data relay satellite.

Three categories of ground station configurations may be envisioned to support the various experiments. They are:

a) A complex of existing MSFN and STADAN stations comprising a coverage network.

b) One or two special stations or specially-modified MSFN/STADAN stations.

c) A multiplicity of sources within a specific geographical area.

In all cases, the experiment data can be maximized by maximizing the contact time between the laboratory and the ground station complex. Orbital parameters are a major factor in determining the viewing time available per pass as well as for a typical mission duration of seven days.

The inclination of the orbit plane to the equator is the most obvious way (but not the only way) of obtaining coverage at latitudes removed from the equator. However, orbital inclination (especially at low altitudes) subjects the orbit to certain gravitational forces which tend to disturb the orbit relative to the earth. Thus, the orbit plane (line-of-nodes) may move about the axis of rotation (regression) or the orientation of the line of apsides may change (precession), or the orbit inclination may change due to the oblateness of the earth.

The altitude of the orbit is directly related to the viewing time from any one ground station. For example, a threefold increase in altitude results in (approximately) twice the viewing period. In general it is not possible for a ground station antenna to view the horizon, being limited either by multipath reflections or obstructed by local terrain. Minimum elevation angles are generally restricted to $\gtrsim 10$ degrees.

It is possible to increase altitude (and the viewing time) over a portion of the orbit without increasing the orbital period by employing Shuttle elliptical orbits.

Many peripheral factors were considered in selecting an optimum CNRL orbit or in bounding acceptable orbital parameters. These included:

- Maximum doppler frequency
- Viewing time by ground stations
- Location of ground targets, stations, tracking, data dump, etc., facilities
- Eclipse periods
- Range safety constraints
- Geographical coverage
- Shuttle Orbiter capabilities.

The desires of each individual experiment, insofar as orbit parameters are concerned, will vary widely. To carry a multiplicity of experiments on any single Sortie Lab flight requires some compromise on the part of one or all experiment principal investigators. The following discussion on RFI and propagation experiments suggests the extent of the compromises, penalties, and tradeoffs required.

Objectives: Survey, identify, and characterize RF noise sources within the CONUS under various (day/night, seasonal, annual) conditions.

Solution: Select a set of orbital parameters which will guarantee a maximum of CONUS coverage under selected time-of-day conditions.

Objectives: Measure RF propagation elements under various weather conditions (clear, cloudy, rain, snow) at various latitudes, and various ionospheric (sunspot activity) conditions using a limited number

of pre-selected ground stations; one contact per orbit desired.

Assumptions: A minimal set of four existing ground stations (STADAN/MSFN) plus a minimum number (2) of special stations.

Solution: The selection of orbital parameters and of ground stations are interdependent. The tendency should be to utilize existing stations as much as possible. Special stations would be utilized to extend latitude coverage or to improve contact time.

Mission operations analysis for all seven experimental classes on early CNRL flights indicated that some useful data would be obtained for all the point measurements within the seven experiment classes for Shuttle/CNRL orbits within the range of 100 to 470 n. mi. altitude and 0 to 90 degrees inclination. However, taking the most important factors into account, it is a general recommendation that the CNRL early flights be planned for orbits of:

200 to 300 n. mi. — altitude
30 to 60 degrees — inclination

with specific conclusion that a daily-repeater orbit of 260 n. mi., circular, 35 degree inclination, should be selected as the baseline for Comm/Nav research on Shuttle mission for the early CNRL.

ORBITAL PARAMETER	REASON FOR SELECTION	PENALTIES FOR OTHER PARAMETER VALUES
i = 55 Degrees	CONUS Coverage; Low Precession of Perigee	$< 55^{\circ}$ may lose Northern U.S. coverage due to increase rate of precession $> 55^{\circ}$ involves payload weight penalty. $< 48^{\circ}$ does not cover CONUS.
$h_p \leq 100$ NMI	Target Resolution (Spatial and Energy)	Degraded resolution or Larger Antenna/More Sensitive Receiver
Perigee in North	Same As Above	Same As Above
Line of Nodes	Preferential Day or Night Coverage	Non-Optimum Time-of-Day coverage
Orbital Period (Apogee Altitude)	Adjust for ≈ 90 Minute Period (Interleaved Ground Track - 10°/Day Regression)	Non-Optimum CONUS coverage

Selection of Orbital Parameters for Terrestrial Sources of Noise and Interference

ORBITAL PARAMETER	REASON FOR SELECTION	PENALTIES FOR OTHER PARAMETER VALUES
$i \geq 60^{\circ}$	High Latitude Coverage Important	$< 60^{\circ}$ would lose important Geographic and Geomagnetic Variations.
$h_p = h_A = 200$ NMI	Constant Altitude (Circular Orbit) Simplifies Data Reduction	Lower Altitudes May Not Include F_2 Layer Variable Orbit Altitude Will Complicate Data Processing
Orbital Period	Adjust Altitude and Inclination and Maintain to Insure Repetitive Ground Trace	Lost Contact Time or Unfavorable Space-To-Ground Geometry
Line of Nodes	Maximum and Minimum Ionosphere Density (Noon and Midnight)	Terminator Orbit Would Not Reflect Diurnal Variations In Ionosophere.

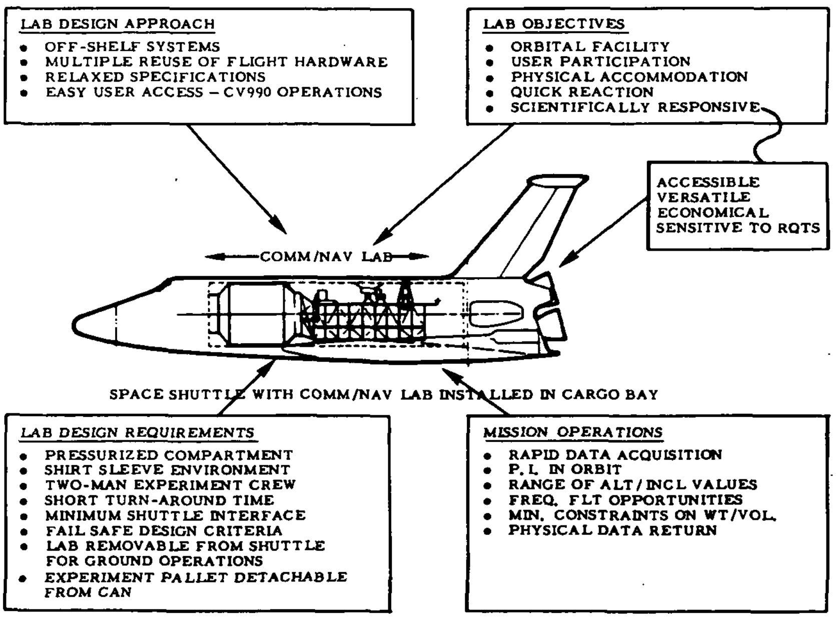
Selection of Orbital Parameters for RF Propagation

CNRL Conceptual Design (Task 5)

While the ultimate space laboratory may accommodate a large list of experiments, the first (Early) Comm/Nav Research Laboratory (CNRL) may be small and rudimentary. A prime objective should be to conceive a laboratory design which can evolve in time, and grow in size and diversity as new experimental needs and capabilities arise. This laboratory evolution can take place in two dimensions:

1) Within an existing configuration and size, expansion or extension of the laboratory's capability to accommodate a particular class of experiment to new frequencies, new parameters, and increased accuracies, and

2) Laboratory configuration and subsystem changes to allow for the addition of new types of experiments not previously included.



The Shuttle Supported Laboratory Offers a Unique Opportunity for the Effective Conduct of Comm/Nav Space Research

The study concentrated on the definition of the Early CNRL as opposed to giving equal treatment to Early, Growth, and Total Labs.

Summary information on the three types of CNRL is given below:

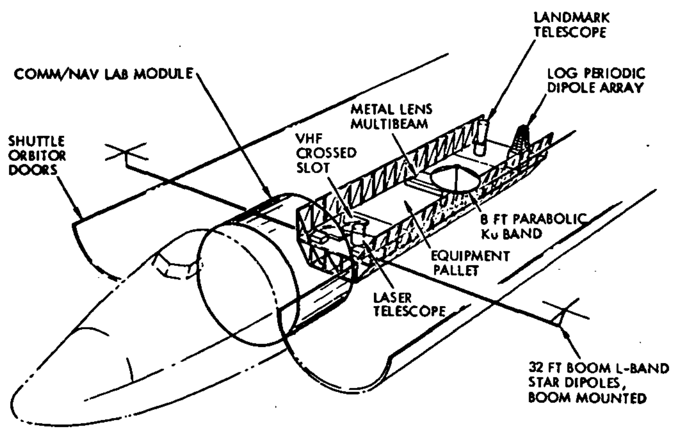
	EARLY LABORATORY	GROWTH LABORATORY	TOTAL LABORATORY
Time Period for Orbit Operations	1980 - 1985	1985 - 1990	1990 →
Launch and Earth Return	Shuttle Orbiter	Shuttle Orbiter	Shuttle Orbiter
Support On Orbit	Shuttle Orbiter	Shuttle Orbiter or Space Station	Shuttle Orbiter or Space Station
Crew Size	2 experimenter crew	2 to 4 experimenter crew	Up to 6 experimenter crew
Mission Duration for Lab	7 day Sortie	1 month to 1 year	2 to 10 years
Experiment Classes Accommodated	4 to 7	Up to 12	All 18
Lab Interfaces with Shuttle	Minimum	Moderate	Extensive
Lab Estimated Weight	17, 000 to 20, 000 pounds	20, 000 to 25, 000 pounds	25, 000 to 60, 000 pounds
Subsystems	Developed, off the shelf	Early Lab subsystems with update	Space Station subsystems
Automation	Minimum	Increased automated events	Highly automated
EVA	None scheduled	Some EVA	Scheduled EVA
Commercial Equipment Modified for Space	Some	Increased use	Significant amount
Maintenance	None planned	Some scheduled	Routine maintenance/repair
On-board Data Processing	Some	Increased use	Extensive use
Configuration Description	MSFC Sortie Lab. Pressurized module plus pallet. Operated in Orbiter bay is the baseline, but could rotate 90° out of bay for better performance.	MSFC Sortie Lab extended and improved. Could also be unmanned/free-flying from Orbiter or Space Station. Growth lab could include a family of host vehicles.	Large pressurized module attached Space Station. Complete research facility in space.
Orbit Performance	Alt. and incl. tied to Shuttle Orbiter limitations. Alt. range 100 to 470 nautical miles. Incl. 0° to 90°.	Shuttle attached labs are tied to Shuttle limitations. Free-flyers could go to geosynchronous altitude via Tug.	Alt. and incl. tied to Space Station limitation. Nominal orbit is 270 nautical miles, altitude at 50° incl.

Comm/Nav Research Laboratory Summary Design and Operations Information

Early Laboratory – Shuttle Orbiter In-Bay Configuration

An Early Communication/Navigation Research Laboratory is contemplated as a Space Shuttle supported, general purpose, reusable, laboratory that could accommodate a wide variety of Communications and Navigation experiments.

Considering equipment weight, volume, and needed services and also taking into account the two-man experimenter crew time available on a seven-day Sortie mission for experiment related activities, an Early Laboratory baseline configuration was developed to accommodate the seven experiment classes selected for early missions.



Comm/Nav Research Laboratory Operating from In-Bay Position with the Shuttle Orbiter. Pallet Shows Possible Antenna Locations.

The laboratory features two major configuration elements, a pressurized habitable Sortie Module and a support structure Pallet for external equipment. Configurations of the equipment layout were examined utilizing the NASA/MSFC provided concept of the Sortie Lab.

The important features of this laboratory are:

- 25 ft. long, 14 ft. diameter pressurized module which houses the crew station experiment operation displays and controls; experiment unique transmitters and receivers; laboratory common core equipment, and laboratory supporting subsystems. These subsystems consist of structure, environmental control/life support, thermal control, electrical power, communications and data management.

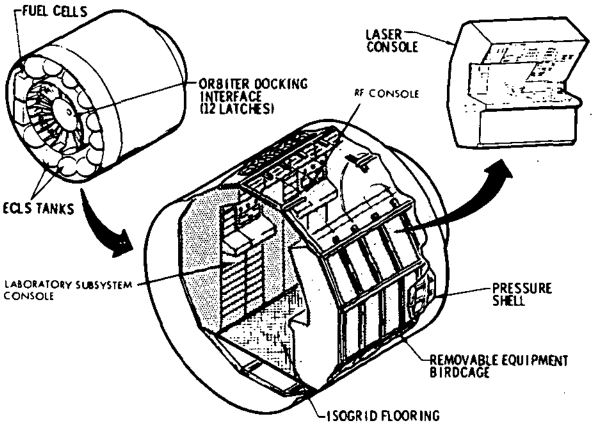
- 8 ft. diameter entry hatch for access of the crew to the Shuttle Orbiter flight deck.

- Removable end dome with an observation window for viewing the bay area.

- 30 ft. long experiment pallet attached to the pressurized module end dome. The attached points for the various antenna mounts are provided by cross truss supporting members. This elevation is necessary in order to improve the antenna field of view from the cargo bay. The eight foot parabolic antenna is launched in a stored position pointing down into the pallet and then erected on orbit. This antenna field of view covers a 54 degree cone of rotation about its boresight normal axis. The 18 inch reflective laser telescope is gimbal mounted in a thermally insulated stable housing with a sealed light pipe system passing through the pressurized module end dome and into the laser console installed in the pressurized module. The critical length of waveguide runs for X-band (and above) antenna systems imposes a requirement to detect and down convert or amplify in housings placed at the base of the antenna. Lower RF signals will then be brought into the pressurized module via coaxial cable.

This configuration is designed to keep the payload (pressurized module plus pallet) within the Orbiter cargo bay. Only the interferometer booms, with the L-band star dipoles at each end, are extended from the bay with all other systems attached at fixed points to the pallet. In this configuration the overall payload length is 55 feet. The cargo bay dimensions permit growth up to 60 ft in length, if required.

The laboratory interior is designed for maximum experiment reconfiguration flexibility. Separate RF and laser work stations are provided and are attached to a removable "bird-cage" structure.



Early Comm/Nav Research Laboratory-Interior Arrangement

The length of the laboratory's pressurized shell is approximately 20 ft with end structures of 2-1/2 ft. The laboratory interior has a one level horizontal floor about 50 inches above the laboratory center line and features an open mesh isogrid panel such as will be used in the Skylab vehicle. The interior includes three display/control consoles (laboratory systems, RF experiments, laser experiments) a workbench, experiment common core and unique equipment other than the antenna which are mounted exterior, and the laboratory's supporting subsystems. The equipment/instruments which are peculiar to

Comm/Nav research are mounted to a "bird-cage" type structure which can be removed at the end of the mission. The laboratory structure and its basic subsystems can then be used for other disciplines (say material sciences) on subsequent Shuttle flights.

Over 240 cubic feet of RF console volume is available to accommodate approximately 100 cubic feet of experiment equipment. The remaining volume allows for ventilation and provides expansion capability. Equipment panels total approximately 10, 250 square inches of console surface.

The laser console volume is 156 cubic feet, with the lower cabinet housing the optic components and upper cabinet for monitoring and control equipment plus support electronics. About 75 percent of the panel surface is occupied.

Early Laboratory – Shuttle Orbiter Out-of-Bay Configuration

The In-Bay CNRL configuration allows the Shuttle Orbiter to fly in a propellant-optimum flight attitude. This approach, however, tends to place the sensors/antennas in or near the cargo bay door-sill plane of the Orbiter. This allows adequate field of view for the antennas for Earth sites within 40 degrees to 60 degrees of nadir, but restricts the field of view for some antennas in the vicinity of the horizon and of any antenna required for relay satellites. Maneuvers to make other satellites visible to the antennas would have an impact on stabilization propellant consumption and on simultaneous earthward fields of view. Configurations based on deploying the NASA Sortie Module and pallet were not considered.

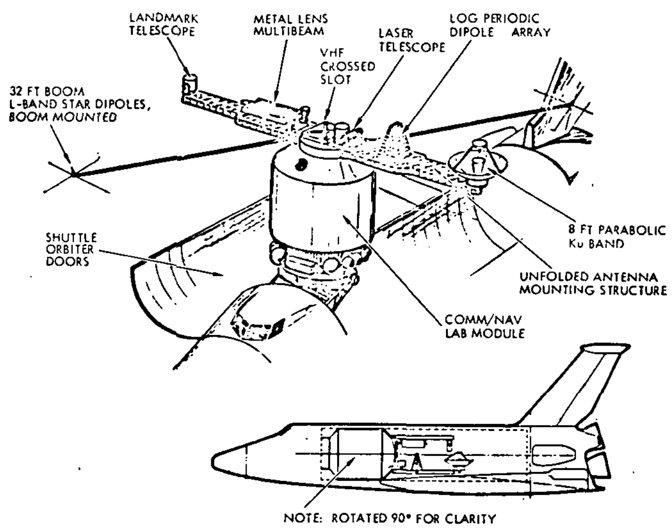
In recognition of the potential antenna blockage, thermal control, and wave guide run problems with an in-the-bay payload antenna farm, an alternate design approach was studied. The pressurized module end dome ring was modified to accept a 16-foot boom structure operated by a double spline gear drive motor system. After a 90 degree rotation of pressurized module out of the Orbiter bay, the antenna boom is erected and oriented normal to the Shuttle longitudinal axis. This orientation offers several advantages. It permits antenna placement well above the Shuttle for fuller RF field of view and at the same time shortens antenna transmission coaxial cable runs to approximately one half that of the in-bay concept. Secondly, this version will permit antenna boresight error adjustments to be made. A precision optical target boresight system is anticipated for this concept. The modified dome mounting would be provided as another experiment unique device equivalent to other exterior hardware.

The disadvantage of this concept relates to fail safe operations. Positive means would have to be employed to insure that the pressurized module with its antenna boom would retract and rotate back into the Shuttle Orbiter bay so that the bay doors could be closed for Earth entry/landing.

An external support structure was generated which is customized to the requirements of the experiment sensors/antennas. One of the key influences lies in the fact that most of the sensors have larger field-of-view requirements along the line of flight than transverse to it. This would indicate some form of support structure that arrays the sensors/antennas transverse to the line of flight for minimum

interferences. The only way to achieve adequate array span and optimum orbiter attitude is to deploy the system out of the Shuttle bay.

The deployed (out of the Orbiter bay) laboratory case considered was based on a specially designed sensor support.



Comm/Nav Research Laboratory Operating Out-of-Bay But Attached to the Shuttle Orbiter

Several concepts were considered and layouts of a folding beam (butterfly) were generated. A feasible arrangement was accomplished but no attempt was made to optimize beam size and sensor arrangement. The end dome closing structure of the Sortie Module has been replaced by a shallow membrane dome and a cylindrical beam support ring. This ring incorporates the support and hinge fittings for the folding beams. This ring also supports within it the VHF crossed slot antenna. On opposing sides of the ring are the hinge fittings, the beam deployment drives and the vernier drives for beam alignment. Each beam has two hinge points with drives in each for redundancy.

Span-wise the beamwidth is stepped and the beam structure consists of two channel beams approximately 15 feet long and spaced 24 inches apart. These two channel beams are flanked by two more beams approximately 8 feet long and spaced 12 inches outboard. The four channel beams are formed into a box structure by facing panels which are an open latice-work of a triangular pattern. This structure should yield a reasonably minimal weight and have good thermal stability, a prerequisite for pointing alignment stability.

The antennas/sensors are located on the two beam structures to minimize mutual interferences both deployed and stowed. One beam mounts the 5-inch optical telescope and the 2 foot x 6 foot (approximate) microwave lens antenna. The optical telescope is mounted on a 2-axis gimbal and has a field of view available ± 90 degrees along the flight path and 90 degrees to one side of the flight path but only 75 degrees to the other side. All parameters exceed the goals of the sensor. The lens antenna is mounted on a single axis gimbal providing ± 90 degrees sweep along the flight path but lateral scanning is done electronically by the sensor itself. Again all pointing goals are exceeded. The other beam structure mounts the 8-foot diameter parabolic antenna, the 5-foot (approximately) log periodic dipole antenna and the 18-inch optical telescope for the laser systems. The large parabolic antenna needs to establish contact with both ground sites and orbiting satellites. For this field of view requirement, the 2-axis gimbal mount was located at the end of the beam. The laser telescope is mounted at the inboard end of the beam structure. It is mounted on a 2-axis gimbal system which incorporates light tube

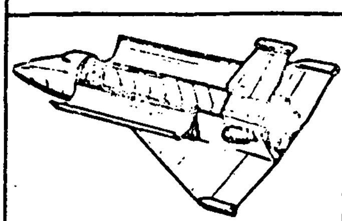
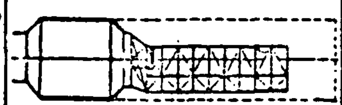
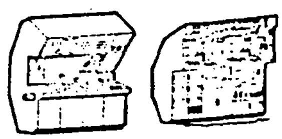
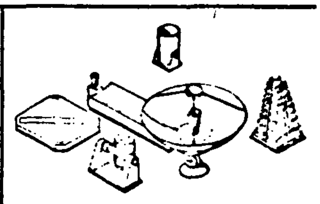
elements. This light tube segments pass the laser signal from any gimbal deflection position to the feed through in the pressure bulkhead and to the internal laser equipment. The laser telescope has a full hemispherical field of view, with its axis to Nadir, except for lateral intrusion by the other antennas on the two beam structures. The full horizon to horizon Earth surface remains unobscured. Two crossed dipole antennas are boom mounted (separately) to booms which are hinge mounted to the outside channel beam in the plane of the main beam assembly. The booms are folded (two segments) along side the beam assemblies for stowage and deploy to angle of approximately 45 degrees with respect to the main beam assembly for use. The extended booms are approximately 32 feet long.

In general, when a significant number of antenna or telescope type sensors are to be flown on a common mission, the large line of flight viewing requirements would place them in a transverse and external (to the Shuttle) array. The concept presented here is not an optimized one and may not necessarily be appropriate to all groups of sensors but is representative of the kind of solution needed.

Early Laboratory Systems Summary

The major elements of the CNRL Orbital system consist of the Shuttle Orbiter, the Sortie Lab/Pallet, and the CNRL equipment. The latter may be divided into the console equipment installed within the Sortie Module, and externally mounted antennas, etc., accommodated on the pallet.

The table below summarizes the major functions performed by each element of the system for a conceptual baseline case together with some of the options which may be appropriate to consider in the future.

	SHUTTLE	SORTIE LAB	CNRL EQUIPMENT	
				
CONCEPTUAL BASELINE	• TRANSPORTATION • USER CREW SYSTEMS • COMMUNICATIONS • VOICE • DIGITAL DATA • ANALOG/VIDEO • DATA MANAGEMENT • STATUS MONITOR • CAUTION/WARNING • STABILIZATION/CONTROL • GUIDANCE/NAVIGATION	• HABITABLE VOLUME • ATMOSPHERE SUPPLY/CONTROL • THERMAL CONTROL • ELECTRICAL POWER/ENERGY • DATA MANAGEMENT (NON EXP) • STORAGE	• PRIMARY OPERATOR CONSOLE • DISPLAY/CONTROL • DATA MANAGEMENT • EXP EQUIPMENT • LASER CONSOLE • LASER TRANSMITTERS • VIDICON • CONTROLS/DISPLAYS • INTERFACE EQUIPMENT	• ANTENNAS • LOW NOISE RECEIVERS • TRANSMITTERS • OPTICS • INTERFACE EQUIPMENT
OPTIONS	• ELECTRICAL POWER/ENERGY • ATMOSPHERE SUPPLY/CONTROL • HEAT REJECTION • GENERAL PURPOSE CONTROLS/DISPLAYS	• DEPLOYMENT (TILT TABLE) • MODIFIED END DOME • ATTITUDE SENSING • EXPERIMENT SUPPORT EQUIPMENT • ADDITIONAL CREW • DATA MANAGEMENT (EXP) • GENERAL PURPOSE CONTROLS/DISPLAYS	• USE OF HOST VEHICLE STANDARD SERVICES • COMPUTATION • DATA MANAGEMENT • DISPLAY/CONTROL • ALTERNATE INTERIOR CONFIGURATIONS	• REDUCED CAPABILITY • PALLET ONLY • MIXED PAYLOAD • DEPLOYED MODE • ADDITIONAL ANTENNAS

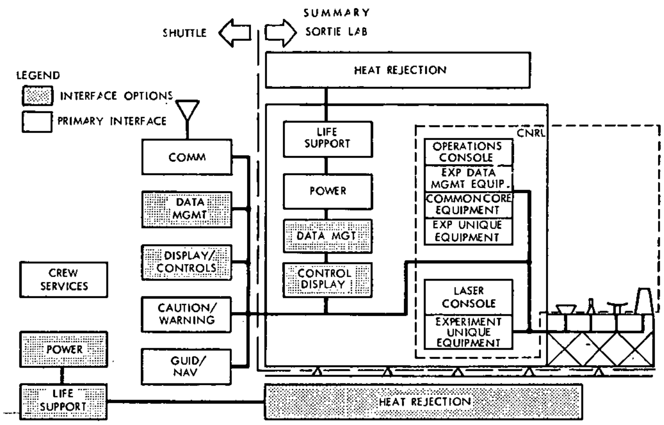
CNRL Orbital System - Summary of Major Functions

This conceptual baseline has been developed to allow the definition of overall mission requirements and operational characteristics of the Laboratory. The primary operator console accommodates the common core and experiment unique equipment needed to conduct investigations in all of the seven candidate, Early Lab experiment classes with the exception of Laser Communications. The nature of the Laser Comm equipment is such that it requires a console dedicated exclusively to investigations in this experiment class.

In addition to antennas and optical devices, other equipment mounted on the pallet includes selected receivers and transmitters (to maximize signal/data quality) and the equipment necessary to interface this equipment with the Sortie Module/Shuttle. As defined at this point in the Study, the CNRL equipment has essentially autonomous capability with regard to experiment control and display, and data management including computer support. The Sortie Lab provides the resources of atmosphere, thermal control, data management and electrical power while the Shuttle provides crew services (hygiene, eating, sleeping, waste management), uplink/downlink communications and guidance/navigation/control.

Results of the study show the capability of this orbital system to be highly responsive to the mission requirements developed for the candidate experiment program. To enable NASA planners to identify the most effective mission plan, however, it is appropriate to identify a variety of options or alternatives to the conceptual baseline. The interfaces between the CNRL and the Host system will certainly change as the Shuttle configuration and the MSFC Sortie Lab designs evolve.

For example, data currently available suggests possible operational constraints in the areas of heat rejection and pointing duration. The ultimate capability of the host system in these areas may influence the design and operational characteristics of the CNRL. Conversely, the importance of defining the candidate experiment program as early as possible should also be emphasized in order to identify critical Shuttle interface areas while it is still possible to influence the design of the various elements of the orbital system.



CNRL Subsystem Interfaces

The CNRL baseline is nearly autonomous with respect to experiment control and display, data management and computer support. The option of utilizing Sortie Lab support in these areas has the attractive potential of reducing CNRL equipment cost, size, and complexity. Development of such an interface will require verification of compatibility with crew usage requirements.

Of all the alternatives to be considered, the impact of "mission modes" on the CNRL configuration is critical. The current configuration fits the "dedicated mission" category. The nature of the CNRL orbital investigations program and equipment fully

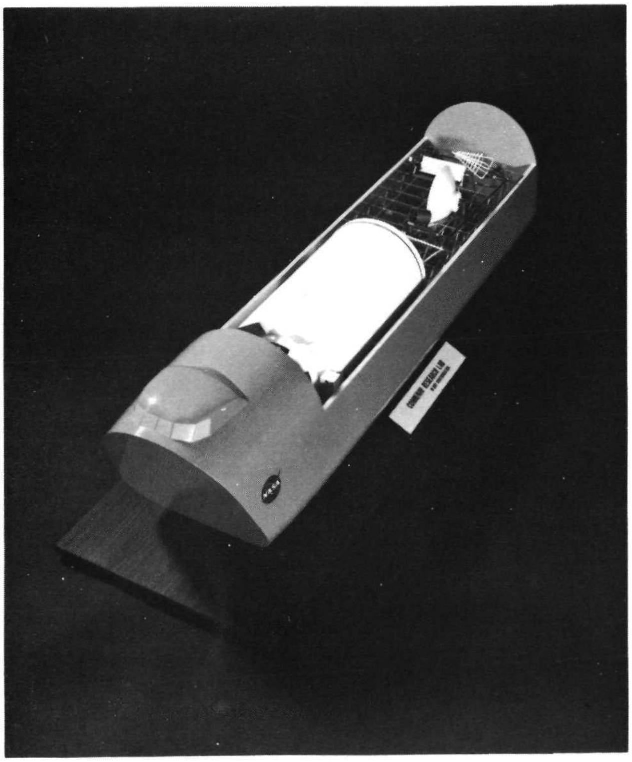
utilizes the crew, supporting resources, and operational capacity of the host systems as defined for the study. The possibility exists that the payload community may choose to emphasize missions other than the dedicated mode, particularly during the early phase of Shuttle operations. The "pallet only" and "mixed discipline" are two to be considered. In the former, only an unpressurized pallet is available in the cargo bay with crew functions performed from the Orbiter flight deck. In the latter, the capability of the Sortie Lab/Shuttle is shared with a number of experiments representing two or more disciplines (e.g., Earth Observations/ Material Science). In both cases, the definition of compatible CNRL mission requirements will change significantly compared to the dedicated mission definition.

With the current interest in early CNRL mission opportunities (including aircraft programs), serious considerations should be given to examining alternate CNRL missions of this kind.

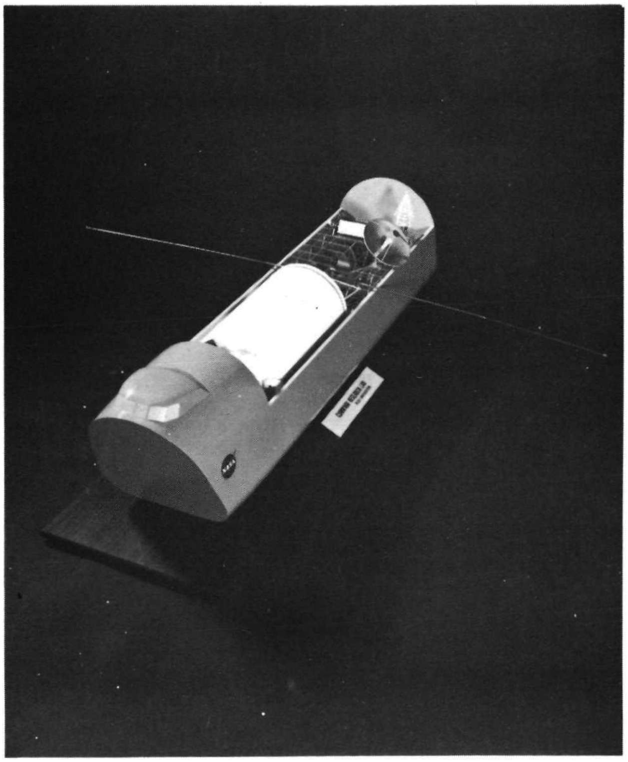
In summary, the CNRL conceptual baseline, together with examination of the options identified, will allow NASA planners to assess alternative mission plans and develop the most effective total system operation.

CNRL Scale Model

As a contract deliverable item, a 1/20 scale model of the Early CNRL configuration was designed, fabricated, and delivered to NASA/MSFC. The model was constructed to depict both the in-bay and out-of-bay configurations.

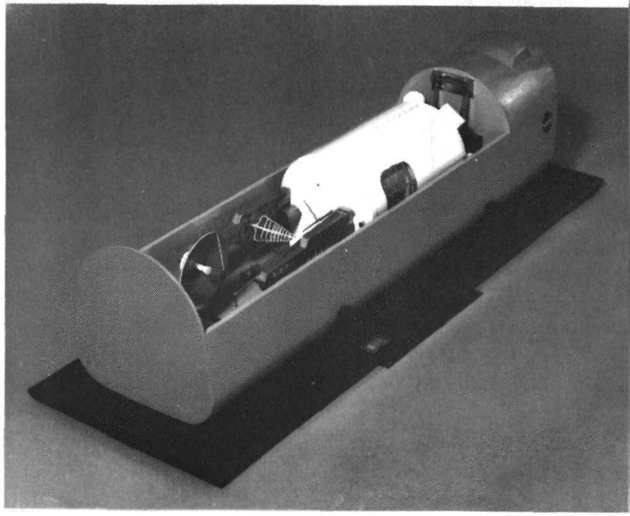


Pallet Equipment Stowed Position

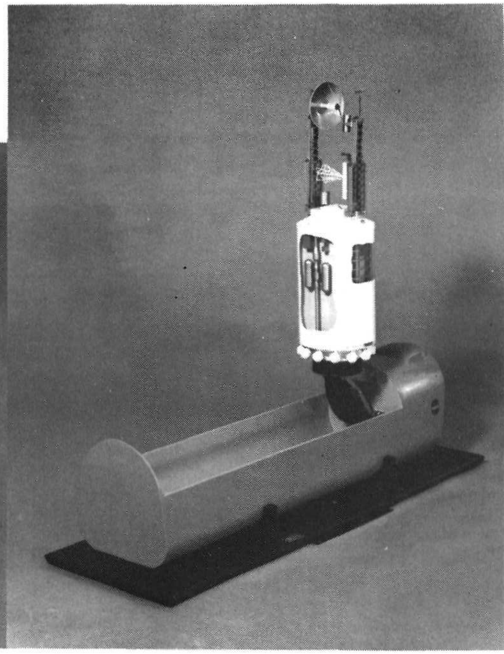


Pallet Equipment Operational Position

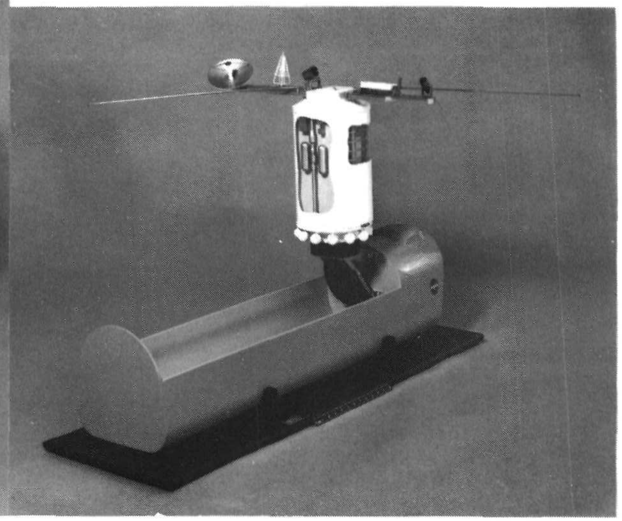
Early CNRL - In Shuttle Orbiter Bay Configuration



Stowed In Shuttle Bay



Rotated Out of Shuttle Bay,
But Antenna Arm Not Deployed



Operational Position

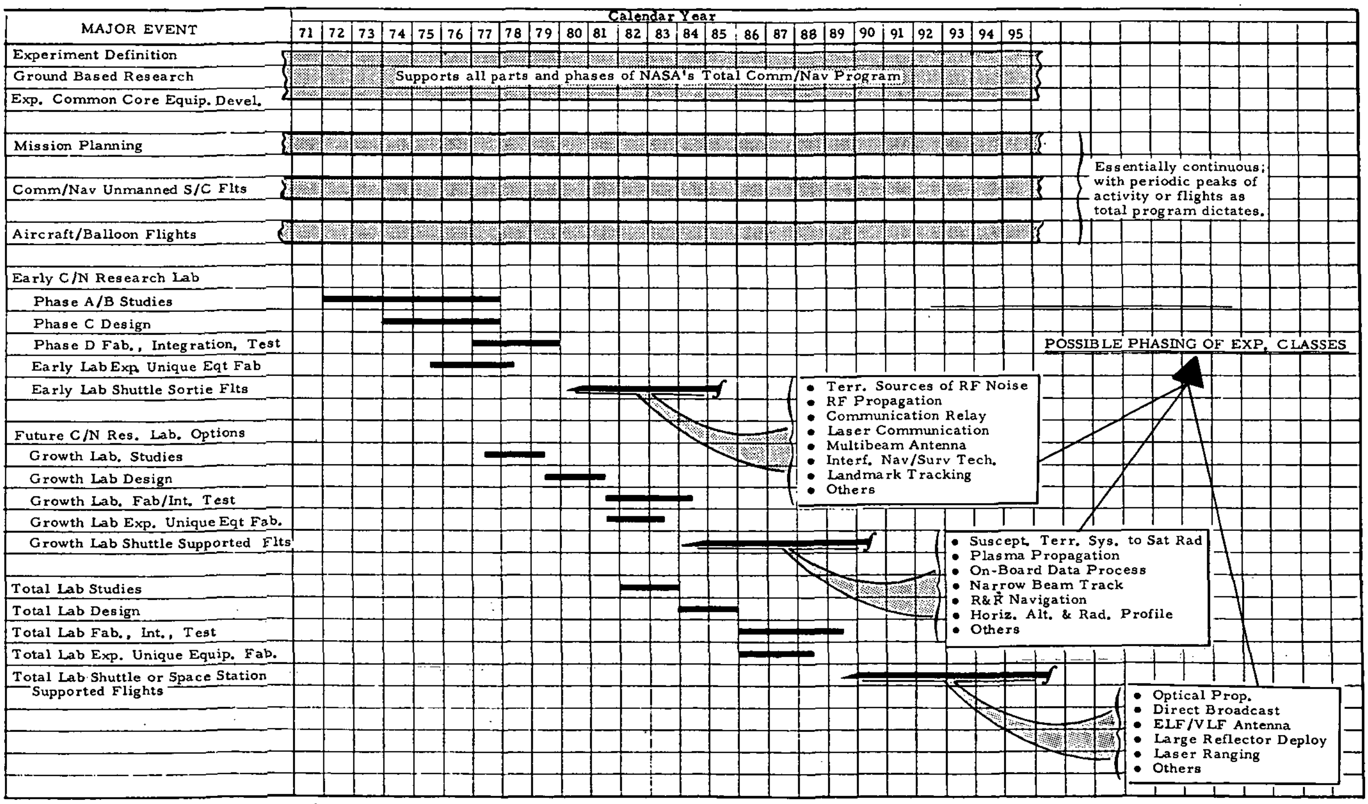
Early CNRL - Out Of Shuttle Orbiter Bay Configuration

Programmatics (Task 6)

A baseline in-bay CNRL configuration accommodating the seven Early Comm/Nav experiment classes was defined to assist in establishing the scope of development time, estimated costs, and supporting research and technology (SRT) required for implementation of the first CNRL flight. Detailed development schedules, cost values, and SRT for the Early CNRL are presented in Study Report Volume IV.

Development Schedule

The study examined three versions of the CNRL — Early Lab, Growth Evolutions of the Early Lab, and the Total Lab. Experiment classes were derived, Study Report Volume II, and assigned for flight implementation to the three laboratories. Arbitrary dates were selected for start of Comm/Nav flights with the three laboratories. The chart below depicts the study derived schedule of milestone events postulated for the three laboratories. The CNRL concept is an integral part of the toal NASA Comm/Nav program. The concept should be planned to complement the ground based, aircraft/balloon, and unmanned spacecraft research and development activities.



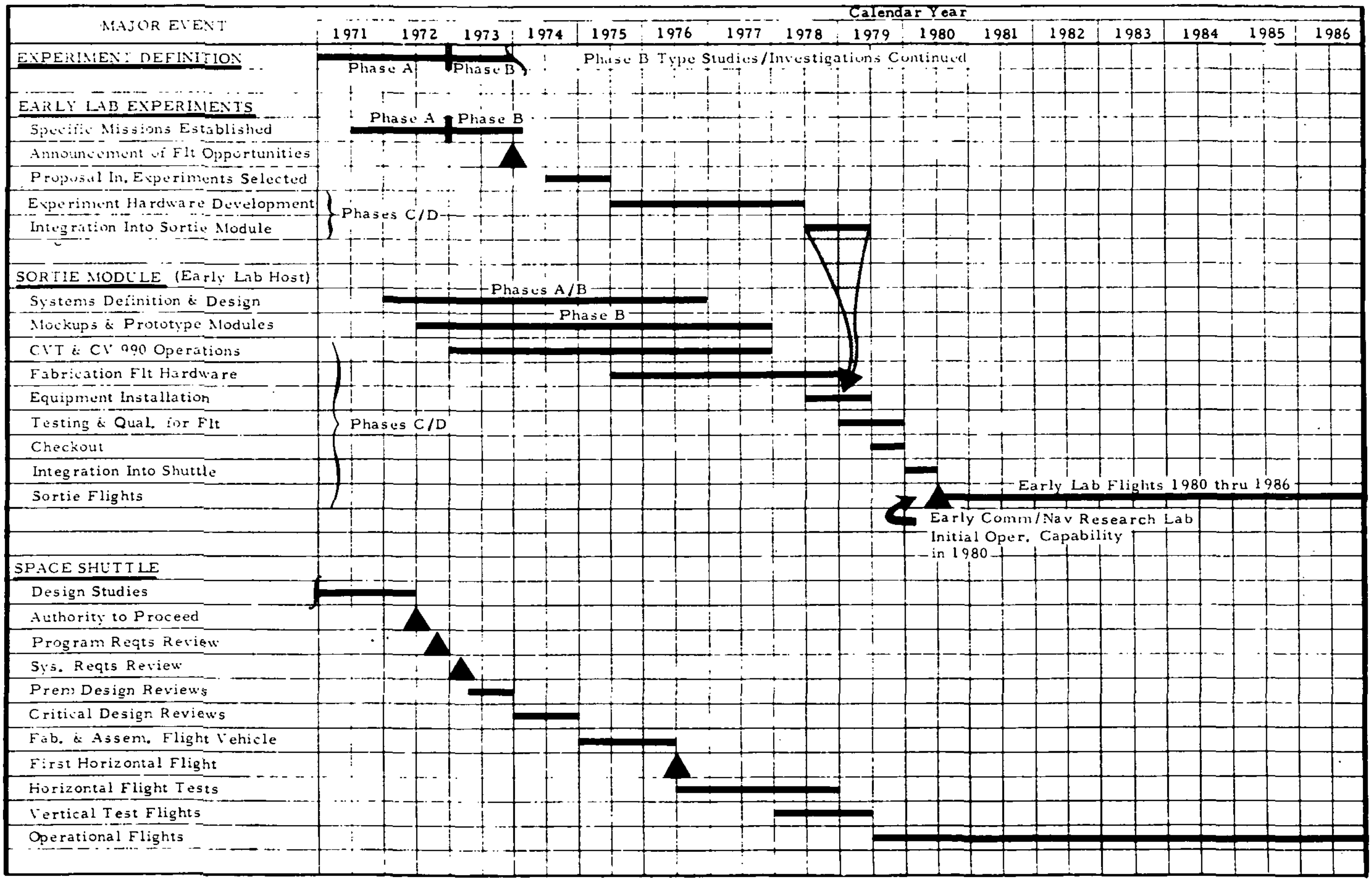
Postulated Schedule of Milestones Relative to Time Phasing of Events for Early, Growth, and Total Communications/Navigation Research Laboratory

Not specifically indicated on above chart is the idea that with concurrent development of laboratory experiment equipment with aircraft and unmanned flight lies the possibility of flying portions or logical assemblies of the experiment equipment on various flight opportunities that might arise prior to Shuttle Laboratory missions.

The Early Laboratory schedule details are shown below as a summary of events and milestones.

This schedule plan is directed at a Sortie Lab dedicated to Comm/Nav research with missions to conduct Comm/Nav experiments starting in 1980.

NASA may fly an austere Sortie Lab on the Space Shuttle development flights in the 1978-1979 period. Space Shuttle operational flights are presently scheduled for late-1979 or early-1980's. Certain Comm/Nav experiment class equipment could be available for these austere (maybe multi-disciplined) Sortie Lab/Shuttle development



Hypothetical Master Schedule for Development and Flights of Early Communications/Navigation Research Laboratory

missions in 1978-1979. Other pre-1980 manned or unmanned spacecraft missions may also provide flight opportunities to develop hardware or techniques. Of the seven experiment classes assigned to the Early CNRL, possibly the equipment for experiment classes of RF Noise Interference, Propagation, and Multibeam Antenna could be flown on 1978-1979 austere Sortie Lab missions. Thus, the key issue of some early applied benefits could be realized.

Early CNRL Equipment Costs

A continuing cost analysis of the equipment/instrumentation for the Early Comm/Nav Research Laboratory was an integral part of the study. The analytical approach to generation of costing data included the use of:

- Cost Estimating Relationships (CER's)
- Cost data banks
- Point estimates
- Inputs from manufacturers of commercial equipment.

The Comm/Nav Research Lab Work Breakdown Structure provided the overall costing format for the identification of program cost items and, as such, served as the collecting point for cost estimates expected to be incurred during the program.

Listed below are the assumptions and/or guidelines that were followed in estimating the equipment and instrumentation costs for the Early Comm/Nav Research Laboratory.

1. The Early Comm/Nav Research Laboratory would be operational in 1979 or 1980 and its initial flights in low earth orbit supported by the Shuttle orbiter would perform research in the following experiment classes:

Class No.	Experiment Class Name
1	RFI — Terrestrial Sources of Noise and Interference
3	Propagation — Radio Frequency
7	Communications Systems — Communication Relay Tests
9	Communications Systems — Laser Comm. Experiments
11	Communications Antennas — Fixed Multibeam
15	Navigation Systems — Interferometric Nav and Surveillance Techniques
16	Navigation Aids — Landmark Tracking

2. The host vehicle laboratory, Sortie Lab, which houses and supports the Comm/Nav experiment equipment and instruments is assumed to be GFE. The Sortie Lab consists of a pressurized module with subsystems plus an attached tubular structured pallet as defined in Volume III.

3. This study concentrates on the DDT&E (non-recurring) and the one-flight production (recurring) costs of the hardware associated with the seven Early Laboratory experiment classes, with no provision for spares or operations refurbishment costs.

4. Cost estimates developed in agreement with the work breakdown structure and stated in Government fiscal year 1972 dollars.

5. No learning curve has been assumed.

6. Costs assume commonality as a primary consideration; that the same prime contractor will have responsibility for designing and producing all the experiment equipment; that the same designs of one mission will be employed to the maximum extent possible for succeeding missions; and that there will be no technology increases during the program. Also, the initial design employs maximum use of existing equipment.

7. Costs are based upon TRW Systems historical cost estimating relationships and similar cost data from McDonnell Douglas Astronautics Company.

8. The estimating methodology is generally applicable to low quantity and low production rate manned spacecraft, and cost improvement due to learning is not included for hardware at Level 5 or above.

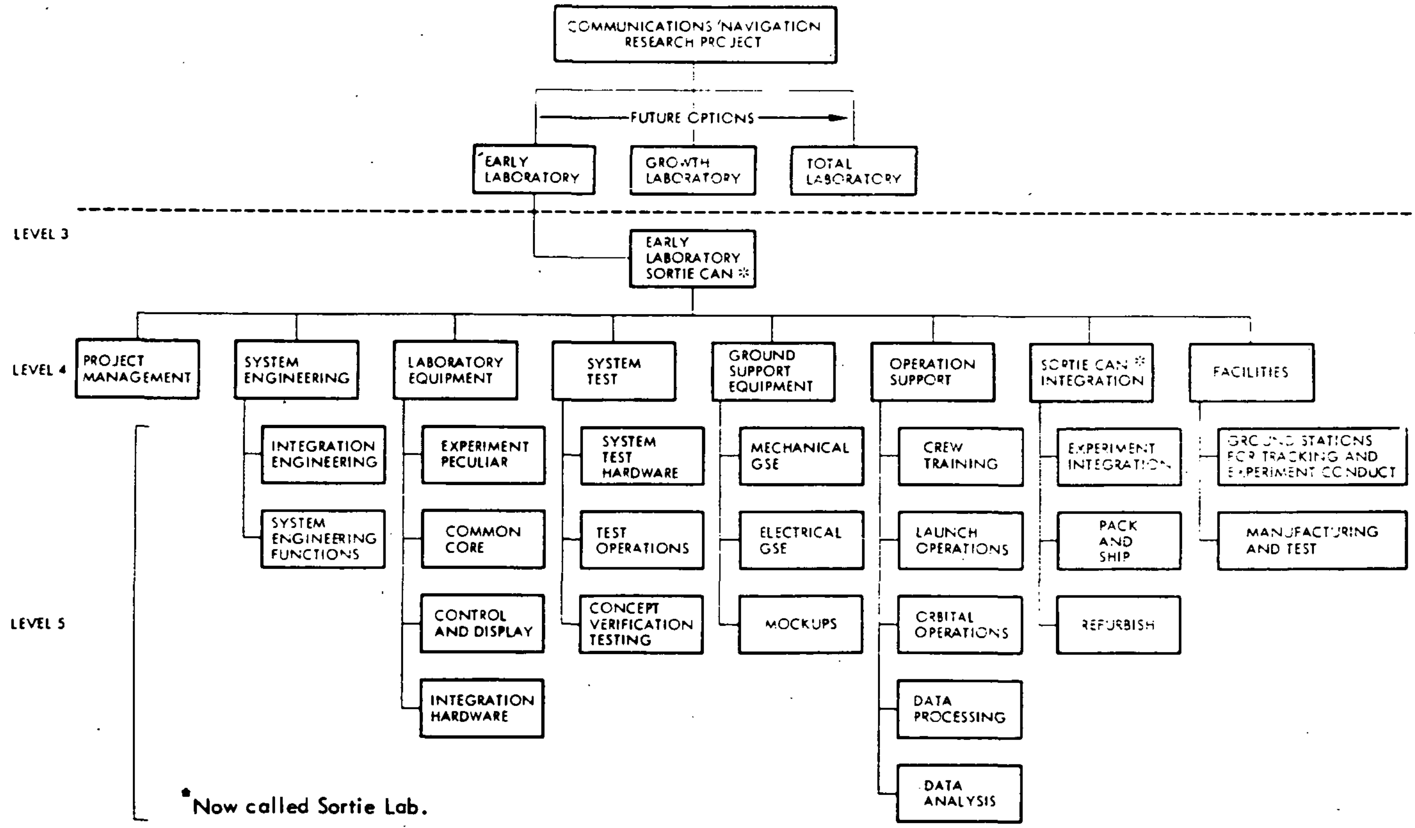
9. All G&A and other overheads and burdens are included in each of the individual cost elements reported.

10. No costs are included for NASA technical or administrative support.

11. No costs are included for operations support, Sortie Lab integration, or specialized ground facilities or system tests, or mockups.

12. Project Management and System Engineering are based on one contractor developing the seven Experiments, related Common Core, and Controls and Displays.

The WBS shown below reflects the principal categories of hardware, services, and other tasks comprising the CNRL project. It displays, in an end-item structured breakdown, functional units of work, Level 4, that form an organizational framework for implementation, management, and control of hardware development, schedule plans and status, and cost accumulation. The WBS units of work are subdivided into manageable elements, Level 5, for which there are technical definition and for which schedules and resource application estimates can be prepared and monitored in reportable packages.



Communications/Navigation Research Laboratory Work Breakdown Structure

The Early CNRL In-Bay Configuration equipment/instrumentation costs for Design, Development, Testing and Engineering (DDT&E) plus production of the first flight hardware for the experiment unique, common core, controls/displays, integration hardware, and ground support equipment were estimated at 55 to 60 million dollars. This included project management and systems engineering.

Cost estimates for specific equipment/instrumentation for the Early CNRL are given in Volume IV.

The estimated \$55M to \$60M Early CNRL costs, in percent, are as follows:

	% of Total Cost
Project Management	8
Systems Engineering	6
Experiment Unique Equipment/ Instrumentation (7 Early CNRL Experiment Classes	43
Common Core Equipment/ Instrumentation	7
Controls/Displays	22
Integration Hardware	2
Ground Support Equipment	12
	100%

The study showed that the unique equipment/instrumentation for the experiment classes would rank, in regard to DDT&E + Flight Unit Costs, as follows:

DDT&E + Flight Unit Costs	% of Exper. Unique Equip. / Instr. Costs
Laser Communication, Class 9, (Most Expensive)	60
Communications Relay, Class 7	20
Landmark Tracking, Class 16	8
Fixed Multibeam, Class 11	6
Interferometer Nav. & Surv., Class 15	3
Radio Freq. Propagation, Class 3	2
RFI — Terrestrial Noise, Class 1, (Least Expensive)	1
	100%

By far the most expensive Class is Laser Communication. It represented well over half the cost of all the unique equipment. If advantage could be taken of related laser communication hardware development being (or to be) sponsored by other (than NASA) U. S. Government agencies, the cost of laser communication experiments on the Early CNRL might be significantly reduced.

The Early CNRL out-of-Shuttle-bay configuration would fly the same seven experiment classes as in the in-bay configuration. However, the NASA-provided pallet would be deleted and replaced with an experiment unique Sortie Lab end dome, end dome ring, and set of deployable antenna arms and drive mechanism. The DDT&E plus unit production costs for these items is estimated at about \$2.7 million.

A comparison was made of the Early CNRL experiment costs (DDT&E plus Flight Unit) utilizing centralized common core equipment versus no common core equipment; that is, each experiment class providing all its equipment, resulting in some equipment duplication. The controls/displays and ground support equipment

remained the same in either case, thereby focusing the comparison on experiment class equipment/instrumentation costs. The comparison showed a savings of about \$5M by using common core equipment. This is another key point in emphasizing the value of the laboratory-facility concept over flights of individual experiments. As the CNRL grows and more experiment classes added, the common core equipment employed will constitute a higher percentage of the total equipment, thus further improving the cost savings.

STUDY LIMITATIONS

This Definition of Experiments and Instruments for a Communication/Navigation Research Laboratory study has been conducted within contractually specified bounds of funding, statement of work, guidelines and assumptions, and schedules. The results obtained are considered valid within these bounds.

However, due to the limited descriptive data available on important interfacing projects, major changes to the list of 18 comm/nav experiment classes and to the CNRL conceptual layouts may occur as pertinent information on the interfacing projects evolves.

No generalization on study limitations is offered. The factors that controlled the output, scope, and conclusions of each of the study tasks must be investigated on an individual basis. These major factors relate to:

1) The difficulty of stating the specific nature of comm/nav user needs in engineering/technology terms for the 1980-1990 time period.

2) The fluidity of the 1980-1990 projects involving the use of automated spacecraft for the conduct of comm/nav space research (ATS series, SATS, CAS, DWS, and TDRS).

3) The emerging condition of performance data on the payload carrying capability of the Shuttle Orbiter. Other orbiter information had to be assumed on means of CNRL deployment to the rotated 90 degree out-of-bay position and on sources of possible contaminants that could affect the experiment data.

4) The development of the design and utilization of the Sortie Lab for accommodating experiment equipment and instrumentation.

5) The continuing assessment of a Shuttle Orbiter flight model. The number and frequency of sortie mission opportunities for comm/nav space research will influence the experiment make-up, objectives, and funding of the CNRL flight program--especially in the early years of CNRL operations.

6) The realism of determining a CNRL experiment program to be conducted 10 years hence and which would complement the then on-going efforts in automated programs. Perhaps this factor is regarded as having the most impact on the study. What to measure, when, how and for what uses dictated equipment/instrument lists which in turn sized the laboratory, scoped the mission, and influenced the laboratory cost.

As the above factors come under better definition, review and updating of study results and conclusions are warranted. This would be especially appropriate on a continuing basis during the development of the Shuttle Orbiter and the Sortie Lab. Similarly, the definition of those comm/nav experiments which would appear to have the most impact on solving user needs and filling technology gaps should be examined as new technology emerges or priorities change.

IMPLICATIONS FOR RESEARCH

The seven experiment classes selected for research on the initial flights of the Early CNRL, and the equipment/instruments, are based, to the extent that was practical and cost effective, on existing technology

and hardware that is expected to be available in a time frame compatible with early mission experiment measurement requirements.

There is virtually no concern regarding the feasibility of the proposal implementation of the Early CNRL. There are, however, particular hardware areas that offer the potential of increased mission data gathering results if SRT work is performed. Study derived Supporting Research and Technology items are summarized on page 41.

SUGGESTED ADDITIONAL EFFORT

Additional work in two major areas is recommended as a continuation of this study. These areas, which are important to planning factors in the overall NASA Comm/Nav research program, pertain to further experiment definition and to alternate CNRL concepts.

The initial design of the Early CNRL is complete. Conceptual laboratory layouts have been established. A 1/20 scale CNRL-Shuttle bay model has been built. The seven selected Early lab experiments and their requirements were necessarily broad in scope. Therefore, it now is important to exercise the conceptual design of the CNRL by defining specific experiments in depth, to see if the laboratory as initially laid out in the MSFC Sortie Module/Pallet combination can, in fact, support and accommodate such experiments. Very possibly, the initial CNRL does not provide all necessary support to an experiment complement different from the seven Early laboratory experiments, but with restructuring of the laboratory a more efficient CNRL could result.

It should be an objective of follow-on effort to review the on-going Communications/Navigation Program to identify any "gaps" in coverage, and to propose experiments which can provide data in these areas and which can benefit from man's presence during the Space Shuttle Sortie mission. The data must be such that its validity is generally applicable to synchronous orbit as well as low earth orbit, since most operational communications satellites are at synchronous altitude.

Any proposed new experiments should be reviewed and those selected as worthy for further consideration then defined in greater detail and the results documented. These experiment definitions will become the driving functions for future laboratory designs. Two alternative approaches to the Space Shuttle Sortie mission payload should be considered and compared: an early, "austere" laboratory and a more sophisticated, more versatile version.

Finally, it should be an objective of any additional work to continue the SR&T, technology development and commercial equipment survey work initiated in this study. In these areas NASA has a continuing responsibility to sponsor and monitor equipment/instrumentation advancement for future space Comm/Nav systems (such as the Space Shuttle itself).

	ITEM NAME	EXPERIMENT APPLICATION OF ITEM: EARLY LAB							FIRST ALTERNATIVES					REMAINDER						OBJECTIVES OF PROPOSED ACTIVITY
		TERRESTRIAL SOURCES AND NOISE	R. F. PROPAGATION	INTERFEROMETER	COMMUNICATION RELAY	LASER-BEAM COMMUNICATION	MULTIBEAM ANTENNA	LANDMARK TRACKING	ON-BOARD SIGNAL PROCESSING	PLASMA PROPAGATION	SUSCEPTIBILITY OF TERRESTRIAL SERVICES	RANGE AND RANGE RATE NAVIGATION	HORIZON ALTITUDE AND RADIANCE PROFILE	OPTICAL PROPAGATION	DIRECT BROADCAST	ELF/VLF	LARGE REFLECTOR DEPLOYMENT	NARROW BEAM TRACKING	LASER RANGING	
1	ULTRAWIDEBAND DIRECTIONAL ANTENNA	X	X		X					X	X									• ESTABLISH AND ANALYZE CANDIDATE CONFIGURATIONS • SYNTHESIZE DESIGN WITH COMPUTER • FABRICATE BRASSBOARD AND TEST ON RANGE
2	WIDEBAND POLARIMETER		X																	• IDENTIFY KEY FREQUENCY SENSITIVE ELEMENTS • DETERMINE APPROACH FOR 10:1 FREQUENCY COVERAGE • DESIGN IMPROVED PROCESSING NETWORK
3	VHF DIGITAL PHASEMETER			X																• IDENTIFY APPROACH FOR RELIABLE HIGH RESOLUTION 60 MHZ RF PHASEMETER • BREADBOARD-DEMONSTRATE-OPTIMIZE
4	REMOTE CONTROL FILTER	X			X				X											• DETERMINE ELECTRICAL NOISE • ESTABLISH PREFERRED DESIGN • FABRICATE AND TEST
5	ADAPTIVE ERP CONTROL								X		X									• IDENTIFY METHODS OF POWER CONTROL FOR FDM AND TDM SYSTEMS • DEMONSTRATE PERFORMANCE
6	REFLECTOR DESIGN AND SIMULATION STUDIES						X								X		X			• INVESTIGATE CANDIDATE MATERIALS • RESEARCH LITERATURE ON DESIGN APPROACHES • SELECT PREFERRED CONCEPT • EVALUATE DEPLOYMENT METHODS
7	SILENT KEYBOARD	X	X	X	X	X	X		X		X				X					• INVESTIGATE ACOUSTIC AND ELECTRICAL NOISE GENERATION MECHANISMS • EVALUATE OPTICAL SWITCHING SCHEMES • SELECT DESIGN APPROACH AND BREADBOARD
8	SOLID-STATE DISPLAY	X	X	X	X				X	X	X	X			X					• EVALUATE STATE-OF-ART IN S. S. DISPLAYS • DETERMINE CANDIDATE • IDENTIFY AND SPONSOR DEVELOPMENT
9	ASTRONAUT LOCATION ROD	←							ALL										→	• SYNTHESIZE ASTRONAUT ACTIVITY IN LABS • DEFINE BASELINE ROD RESTRAINT • INTEGRATE PHYSIOLOGICAL, SAFETY AND WORK FACTORS
10	RFI-EMI PROTECTION (CAN)	X	X	X	X		X		X	X		X				X				• EVALUATE STATE OF ART IN SHIELDING AND FILTERING • REVIEW PRIOR SPACE VEHICLE SIGNATURES • SIMULATE EXPECTED SORTIE CAN EQUIPMENT CONFIGURATIONS TO OBTAIN RFI SIGNATURES • EVALUATE EFFECTS ON EXPERIMENTS AND DEFINE
11	COMMERCIAL EQUIPMENT TRANSLATION	←							ALL										→	• INSPECT REPRESENTATIVE COMMERCIAL CANDIDATES • RESEARCH MATERIALS AND METHODS • DETERMINE REQUIRED IMPROVEMENTS • RUN PILOT R&D - SPONSOR INDUSTRY FOLLOW-ON
12	IMPROVED LASER DETECTOR					X								X					X	• CONVERT RESEARCH DEMO IN BELL JAR TO SPACE-USE HARDWARE • EVALUATE COOLING • DEVELOP CROSS FIELD P. M. T. FOR 1.06 MICRON
13	TUNEABLE LASER					X								X						• DEVELOP LASER TUNEABLE OVER >±10 GHZ HAVING MINIMUM OUTPUT OF 50 MW AT 10.6 MICRONS • INVESTIGATE HEATPIPE AND THERMO-ELECTRIC COOLING
14	IMPROVED UNIVERSAL RACK-TRAY STRUCTURE	X	X	X	X				X	X	X	X			X	X		X		• ADAPT PROVEN, LIGHTWEIGHT, RUGGED, COMPACT "ATR" EQUIPMENT SCHEME TO MANNED C/N MODULE
15	SIGNAL SWITCHING MATRIX	←							ALL										→	• DEVELOP IMPROVED COMPLEX SIGNAL SWITCHING SUBSYSTEM ESSENTIAL FOR VERSATILE LABORATORY
16	IMPROVED DOPPLER ANALYSIS SOFTWARE	X		X					X											• EVALUATE VARIOUS ALGORITHMS FOR IMPROVED SPEED, ACCURACY AND LOW COST. • RE-EXAMINE F. F. T., F. H. T. AND ALLIED ALGORITHMS TRY TO APPLY.
17	EFFICIENT ANTENNA FOR VLF															X				• EVALUATE MATERIALS FOR VLF/ELF ANTENNAS • EXAMINE AND ANALYZE ALTERNATIVE CONCEPTS • DEFINE PREFERRED APPROACHES AND PERFORMANCE
18	ADAPTATION OF EVA MANIPULATORS FOR ANTENNA DEPLOYMENT	X	X	X	X	X	X			X	X	X		X	X		X	X		• DEFINE METHOD OF INTERFACING SHUTTLE MANIPULATORS WITH VARIOUS COMM/NAV ANTENNAS TO OBVIATE NEED FOR SEPARATE DEPLOYMENT/POINTING FACILITIES • INVESTIGATE HOW BEST TO STORE, RETAIN/RELEASE ANTENNA ASSEMBLIES, RESTRAIN CABLE, PROGRAM USE
19	IMPROVED KALMAN FILTER FOR POST-ACQUISITION DATA ACCURACY ENHANCEMENT	X	X	X				X						X				X	X	• EXAMINE EXISTING STATE-OF-ART IN COMPUTER STATISTICAL FILTERING TECHNIQUES - RELATE TO SPECIFIC COMM/NAV EXPERIMENTS • ATTEMPT TO DEFINE IMPROVED ALGORITHMS FOR COMM/NAV LAB USE
20	INTERCHANGEABLE MICROWAVE PACKAGES AND COMMON REFLECTOR	X	X	X	X					X	X	X			X		X			• DESIGN A PACKAGING SCHEME FOR PRECISION EVA SUBSTITUTION OF VARIOUS MICROWAVE HEADENDS ON A SINGLE (COMMON) DISH • EXTEND CONCEPT TO DEVELOP REMOTE HEADEND CHANGES USING SCHEME SIMILAR TO MOVIE CAMERA LENS TURRET

Summary Communications/Navigation SR&T Item Applications